LOAD FORECASTING OF UTTAR PRADESH POWER SYSTEM

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CERTIFICATE

It is certified that this work entitled 'Load forecasting of Uttar Pradesh Power System' by Vinda Prasad Tewari has been carried out under my supervision and that this work has not been submitted elsewhere for a degree.

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ABSTRACT

Load forecasting is an essential pre-requisite for any power-system planning, design and development. Type of forecasting is decided by the time-period under consideration. Approach to short term load forecasting is completely different from long and medium term load forecasting. In this thesis, long and medium term load forecasting of Uttar Pradesh power system has been done, in view of long term planning of Uttar Pradesh State Electricity Board (UPSEB). A review of recent prevailing practices, for long and medium term forecasting techniques along with their uses and necessity, have been presented. It is seen that no technique will yield exact results because of uncertainties of the future, viz. unforeseen contingencies. Accuracy of forecast depends upon accuracy of data.

Depending upon availability of data, the energy requirement and peak load of U.P. Power System, for the years 1983-84, 1988-89 and 1993-94 have been computed using some statistical techniques. Results obtained thus, have been compared with the corresponding forecast given by Central Electricity Authority (CEA).

CHAPTER - I

INTRODUCTION

1.1 Power System expansion planning starts with a forecast of anticipated future load requirements. Load forecasting is an essential pre-requisite for efficient planning and operation of a power system, because the magnitude and characteristics of the load affect the design and performance of the system. A system forecast is necessary to plan the future generation requirement, which forms the basis for planning the main transmission network of the entire system. Estimate of both demand and energy requirements are crucial for effective system planning. Demand forecasts are used to determine the capacity of generation, transmission and distribution system additions, and energy forecasts determine the type of facilities required. Long term load forecasting is essential for any country or state in view of the long gestation periods for the power projects. Short term load forecasting is much more needed for comprehensive and careful operation planning. The knowledge of load demand from a few minutes to a few days in advance is very useful in economic scheduling, real time state monitoring and for security checks, besides its active role in maintenance is well recognised.

Load forecasts are also used to establish procurement policies for construction capital needed and to determine future fuel requirements. In summary, a good forecast reflecting present and future trends, tempered with good judgement, is the key to all planning; indeed to financial success /11/.

In a planned economy, the power forecast will necessarily have to be based on a realistic appraisal of country's future plans on productivity, national incomes and savings, consumption and investment, natural resources, capacity to manufacture equipment indigenously etc. Thus load development in our country or state is intimately linked to economic activity in general and growth pattern of load in intensive sectors such as steel, cement, heavy chemicals etc. in particular. The load demand for electric power should, therefore, be based on the productive sector of economy and needs of population /1/. Load forecast has to be continuously revised with the future changing pattern of economic growth, as power is one of the basic infrastructure for economic development.

In India, the load forecasting made a beginning in a systematic manner, around the year 1955. Now a days the electric power forecast is done at the national and state level by agencies such as Central Electricity Authority,

Planning Commission, State Electricity Boards and Annual Power Survey Committee /2/. Planning organisations of most of the State Electricity Boards are dependent on the load forecasted by above agencies and plan their future transmission and generation projects according to that. The techniques used by these agencies are mainly based on the assumption of taking a base year and then projecting the growth every year based on a certain pattern of consumption.

1.2 In this thesis, the load forecasting, a case study of Uttar Pradesh (U.P.) Power System has been done. The rate of development of any state is directly dependent upon the matching development of power resources. U.P. Power System is the biggest system in our country, having large number of transmission networks and generating stations. Since the location of generating stations and the load centres are not generally close to each other, it is essential to evolve a plan for the integrated development of power resources in the state. Moreover, there have been no conscious attempt to relate the electric load development to other factors of the economy for the purpose of load forecasting by above mentioned agencies /2/ and U.P. State being most populated in India and moderately industrialised, an attempt is made here to correlate some economic and social factors affecting development of load in the state such as state income and

population etc. Depending upon these factors, load forecast of U.P. State has been made. In this thesis depending upon availability of data only long term and medium term load forecast of U.P. Power System have been done using various statistical techniques.

1.3 Now we give a brief chapterwise description of this thesis. In chapter - II, use and needs of load forecasting, factor affecting load development, types and approaches of load forecasting and basic requirement of realistic load forecasting have been described. Chapter -III deals with various methods of load forecasting. In chapter - IV, Load and energy requirement of U.P. Power System have been calculated for the years 1983-84, 1988-89 and 1993-94, using some of the methods described in chapter - III. Based on the result of the chapter - IV, some important conclusions have been made in chapter - V.

CHAPTER - II

LOAD FORECASTING

2.1 LOAD FORECASTING: USE AND NEEDS

Primarily any sort of planning of a power system is in some way or other related to the magnitude and characteristics of the load on that system. The load forecast is, therefore, a vital element in planning various components of an expanding system such as generating capacity, transmission lines and sub-station capacities, so as to meet the increasing demand of system from time to time.

Long term forecasting enables formulation of country's perspective plan on power development and it helps in having a view on the progressive utilisation of country's hydro and other power resources and also use of higher transmission voltage. Medium term forecasting provides the basis of expansion programme of power generating capacity and transmission facilities. The area of power shortage/surplus during the short term period can be identified from short term load forecasting and thus helps in formulating measures for utilisation of surplus power in deficit areas.

Some of other uses of load forecasting are as follows /3/.

2.1.1 LONG TERM FORECASTING

I. It helps in formulating national power policies.

II. It indicates where, when and how much additional generation, transmission, distribution, sub - station capacity and development of distribution network is required.

III. It helps the State Electricity Boards to plan their investments to the maximum advantages and to evolve the optimum tariff for the various categories of consumers.

IV. It helps in investigating the measures so that future demand may be met.

2.1.2 SHORT TERM FORECASTING

I. Framing/Reviewing plans for the establishment of future points of supply from the point of view of their timings.

II. Framing/Reviewing plans for power factor correction at various points in the system as a means of keeping MVA demand changes on imported power to the economic minimum and optimising plant utilisation.

III. In case, the power is being imported from other sources as well, having difference in rates between them, forecasting can help in proper and economic use of such sources.

In more advanced countries, load forecasting is used for variety of purposes such as /3,4/.

(i) Unit Commitment and Scheduling of maintenance thereby deciding the start-ups and shut-downs of power stations several hours in advance.

(ii) Operational planning and interconnections.

(iii) Economic generation scheduling and security analysis.

(iv) Real time state monitoring.

(v) Economic load dispatching in interconnected power systems.

(vi) Estimating surplus and secondary sales.

(vii) Ordering coal or fuel.

(viii) Forecasting revenue, cost of power for operating budget.

(ix) Preparing capital budget.

2.1.3 The forecast of power demand are needed at the following levels :-

(i) Locality or distribution centre level for distribution planning.

(ii) Sub-station-wise forecast for planning sub-station expansion and transmission system.

(iii) System level forecast for planning generating facilities.

Therefore, it becomes necessary to collect data regarding all the planned activities both at Macro and Micro level. All the data collected at Micro level such as localities or distribution centres, are grouped into Macro level such as sub-station and systems. To make these forecasts at different levels, it is necessary to know not only the diversity between consumers but also the diversity between the localities/distribution centres and between sub-stations. The load forecasting is, therefore, tobe made at different levels, so as to assess the national/state requirements to be incorporated in plans and for the purpose of load development. The accuracy of forecast is crucial to any electric utility, since it dictates major system additions. Considering the fact that the developing countries such as ours, have limited financial resources for over-all economic development, the forecast of power demand would have to be very accurate and reliable in order to make full use of what is available under estimates of power demands. Under estimation of power demand may render investments in electricity dependent sectors idle due to non-availability of power and may also result in the loss of revenue from sales to neighbouring utilities. On the other hand, over estimation would lead to unnecessary blocking large investments with

out any immediate return. However, in view of the fact that investments in other sectors utilising power, are considerably more than the corresponding investment necessary for providing the power supply facilities, it is better to take a little optimistic figure in power forecasting rather than a pessimistic one. An accurate forecast also depends on the judgement & experience of the forecaster and it is impossible to relay strictly on analytical procedure to obtain an accurate forecast.

2.2 FACTORS AFFECTING DEVELOPMENT OF LOAD

Such factors which contribute to the development of load in a particular year are so many and can be categorised as natural ones and man made. These factors are mostly interdependent and are such that, the effect of these can not be precisely grouped for next 10 to 15 years in advance, as certain amount of uncertainty is associated with each one of them. Under such circumstances load forecasting will be just rough estimates of the future requirement. It is however, desirable to improve the accuracy of the forecast as mush as possible. The factors which effect the development of load significantly are /5/ :-

(i) Pattern of energy consumption.

(ii) Level of country's economy.

(iii) Degree of industrialisation and its

future scope.

(iv) Incentive available for setting up of new industries.

(v) Position of foreign exchange and its effect on industrialisation.

(vi) Existing status of urban and rural electrification and future target to enhance the same /6/.

(vii) Scope of electricity for agriculture purpose.

(viii) Extent of natural resources available and the programme of their exploration.

(ix) Pattern of national and state plans regarding execution of such schemes which involve use of power.

(x) The rate of availability of electric power.

(xi) Financial capacity of the people to afford and run power consuming installations such as industries, irrigation pumps, thrasher, refrigeration and air-conditioners etc.

(xii) Population and technical know how of the people.

(xiii) Weather conditions.

It can be seen that the forecasting which depends on the above factors can never be an accurate estimate.

In the ultimate analysis, however, much depends on the forecasters ability to translate the plans for various economic activities into meaningful forecast of power demands.

2.2.1 Future load demand is dependent upon a number of socio-economic, technological and other factors. These factors should be studied in detail by a planner to forecast load. Some of these factors are as follows :-

(i) Load factor.

(ii) Diversity factor between users, transformers, feeders and sub-station etc.

(iii) Maximum demand and demand factor.

(iv) Population and urbanisation trend.

(v) Saturation limits for the sectors.

(vi) Fringe growth of load.

(vii) Pattern of past load demands.

(viii) Development of non-conventional sources of energy.

Diversity factor for various categories of consumers such as domestic and commercial lighting, small power and large power users are to be evaluated. These factors vary from area to area and season to season. Load factors for each type of power consumers are to be known to evaluate the energy requirement. The present trend is to

assume certain approximate figures for these factors. Very little statistical field data based on actual measurement is available. However, these can be precisely estimated by statistically valied sample tests.

2.3 TYPES OF FORECASTING

Forecasting is simply a procedure for quantitatively defining future loads. Depending on the time period of interest, load forecasting may be classified into the following three categories /7/ ;

I. Long term forecasting covering period of 10 to 20 years.

II. Medium term or intermediate forecasting covering period of 5 to 10 years.

III. Short term forecasting covering period of 1 to 5 years.

Now a days short term forecasting also refers to short range forecasting which covers the period of forecast in weeks and hours. But this short range forecasting is less significant for Indian conditions as daily load curve does not change much.

Unlike other industries, the electric supply utility does not have the freedom to regulate control on its business on account of its public utility character and associated statutory obligations. Moreover, it is not

possible to estimate the degree of accuracy of the result of a study for determining long range load forecast in a power system. It is, therefore, necessary to carry out the long term forecast continuously with much degree of accuracy for system planning etc. and make studies of alternate methods for system expansion. The absence of long range forecast could create regional imbalance and bottlenecks despite adequate overall investment. Medium term or intermediate forecast is used in formulating immediate power development programme.

The approach to long term forecast is quite different as compared to short range forecast. The short range forecast is required for day to day system operational planning and is affected by seasonal variations, weather conditions and industrial relations etc., while long term forecast is greatly influenced by what has happened in past years. Long term forecast has to be made without undue bias on account of the immediate past, but what the load growth has been for the last 10 to 15 years.

2.4 CHOICE OF SUITABLE METHOD

Choosing a forecasting technique to use in establishing future load requirements is a non-trivial task in itself. Depending on the nature of load variations, one particular method may be superior to another. Before

choosing a particular method, a basic understanding of how a load behaves, is essential. Load forecasting is mainly the projection of the past trends suitably modified by the present conditions and future development plans. As so many man made and natural unforeseen factors contribute to the development of load in a particular region that, no one method , can be taken as suitable for the purpose of load forecasting. Alternate methods can be employed to arrive at reasonably correct figure and for a check as well. Thus, analysis of statistical data relating to development in the past, a close study of prevalent conditions and a scrutiny of future development plans coupled with field survey, may lead to a fairly accurate guess of the load demand.

As regional disparities of economy within the country/state also usually sought to be removed through planning and economic considerations alone don't dictate the investment decisions in various sectors. In view of the above, the planned rate of growth of various elements of the infra-structure of economy differs sharply from the past trends. As the statistical techniques postulate future growth on the basis of the past trends, they don't lead to reliable forecast.

The method chosen has to be simply economical, least time consuming and at the same time yield detailed

forecast with reasonable and uniform accuracy. The choice of method of forecasting also depends on the purpose for which study is conducted and the length of period of forecast.

Choosing the best technique for a given utility, once again, requires, good judgement and a knowledge of the advantages and disadvantages of various available methods. Once a method has been chosen, the forecaster must always revaluate its effectiveness, because forecasting techniques can out-live their usefulness, as a result of either drastic changes in a system or improvements in available methods /11/.

2.5 APPROACH TO LOAD FORECASTING

The following approaches are provided before going into details of load forecasting methods /3/ :

(i) Peak Load approach

(ii) Energy approach

(iii) Total Load Components approach /11/

In a system with predominant Hydro generation, the Peak load approach is normally used and in case of Thermal predominant, the Energy approach is preferred.

In peak load approach i.e., predominating hydro generation, it is considered that if the peak requirements are met, the energy requirements will be met automatically, while in a system which entirely depends on thermal

generation resources, every kwh of energy produced has a real measurable cost and the important element to forecast is, therefore, energy. In both the above cases, peak load or energy may be calculated.

The present day practice, is, to adopt the energy approach. This may be to some extent due to very high capita consumption in those countries where, it is assumed that if the energy requirement are satisfactorily met, the available generation capacity usually takes care of the peak demand, specially where there is interconnected operation of a group of power systems and any increase in peak demand can be absorbed by the interconnected system without difficulty.

The advantages of using energy as primary forecast and obtaining the peak demand forecast from it are, that, energy tends to be much less erratic, is considered a better trend growth indicator and is readily related to demographic and economic factors, using energy data broken down into classes of services, areas etc. The advantages of separately forecasting the peak load are that it is a more direct method and can be related directly to such weather variable as temperature etc.

2.5.1 PEAK LOAD APPROACH

The peak load approach to the load forecasting, necessitates, working out the demands under the various

categories of load, starting from the connected load in the category, by adopting suitable demand factors and evolving the locality demands, sub-station demands, system demands and finally the grid demand, adopting appropriate diversity factors and allowing reasonably for the losses in the distribution, transmission and transformation, The continuous generating capacity available to meet the expected power demand is usually worked out after allowing for station anxiliaries and the shortage or surplus in capacity to meet the anticipated demand. Though the peak load approach to load forecasting broadly serves the purpose of planning additional generation, it suffers from a major draw back that too many assumptions right through the forecast in the form of demand factors for the various categories of load, diversity factors of locality, sub-station, system and grid levels, losses in distribution, transmission and transformation at different stages and finally the generating capacity set apart for station service, tend to take the forecast wider of the mark whatever care is taken to ensure that the assumptions are as realistic as possible.

2.5.2 ENERGY APPROACH

The energy approach to load forecasting seems to have one distinct advantage of having no diversity problems and consequent assumptions. Usually, as an area grows, trends in growth appear and such trend can more easily be

established in terms of energy for different categories of load as recorded data in terms of energy used will be available while no such recorded data is available for the demand of any particular category of load. For assigning at the total energy requirements at different levels of locality, sub-station, system and grid, it is only necessary to add the energy requirements progressively. Then energy losses and station auxiliaries of energy which can be estimated with reference to recorded data for past period, may be added to arrive at the total energy to be generated and by making only one assumption for the annual load factor for the grid system, the peak demand to be met can be worked out. The energy approach also makes it easier to forecast the requirement of new industrial loads as these can be worked out directly with reference to the production capacity or output of the product bringing into the picture any load factor which otherwise, has to be assumed.

Energy forecasts tend to be developed using correlation and extrapolation, primarily, tempered with sound projections of future conditions. Generally to arrive at a total energy forecast, the forecasts for the three major classes of customers (residential, commercial and industrial /11/) are determined and then combined. Each class is forecast separately because of different characteristics associated with these classes.

Residential energy requirement are dependent on many things, but the major factors are :- (i) Residential customers, (ii) Population per customer and (iii) Per capita energy consumption. Clearly, if each factor were known for the forecast period, then the forecast of residential sales could be obtained simply by multiplying the three factors. To obtain the forecast values of these factors, either simple curve fitting methods or more sophisticated regression analysis can be used. Such an approach to residential forecasting is usually referred to as the 'Population' methods.

An alternative approach, known as the 'Synthetic' method, requires a more detailed look at each customer. For this method the major factors are :- (i) Saturation level of major appliances (ii) Average energy consumption per appliance (iii) Residential customers. Once again, if these factors are extrapolated into the future and multiplied together, the result is the desired forecast of residential sales. Clearly, the synthetic method requires a great deal of data collection to define the relative affluence of customers.

To forecast commercial sales, a host of different approaches may be taken. Perhaps the simplest is based on the fact that commercial establishments are usually service oriented; hence growth patterns are usually related closely

to growth patterns in residential sales. Specifically, one method for forecasting future commercial sales is to extrapolate the ratio of commercial to residential sales into the future and then multiply this forecast by the residential sales forecast to obtain the desired commercial sales forecast. Another approach is to extrapolate historical commercial sales, since this information is frequently available.

Of all forecasts, obtaining an accurate industrial sales forecast is by far the most difficult. Industrial sales are very closely tied to the overall economy, and we all know how unpredictable the economy can be over selected periods. Even in view of these difficulties, many approaches have been and are used by forecasters to develop industrial sales forecasts. Two such approaches are /11/:- (I) Multiply forecasted production levels by forecasted energy consumption per unit of production and (II) Multiply forecasted number of industrial workers by forecasted energy consumption per worker.

Whether these particular approaches work, probably depends on the type and location of the industry involved. In fact, in many instances, the historical industrial sales are decomposed into sub-classes to facilitate an accurate forecast of each component. This step is particularly important if a utility serves a broad spectrum of different

types of industries /11/.

2.5.3 TOTAL LOAD AND LOAD COMPONENT APPROACH

Another approach to the load forecasting may be the total load. Total load may be forecasted by combining forecasts of appropriate certain load components or total load forecast may be directly obtained from historical total load data. Typically, the components consists of types of customers, geographic areas, etc. An advantage, claimed for the total load approach is that it is easier to use and totals are much smoother and more indicative of overall growth trends. On the other hand, an advantage of component approach is that, abnormal conditions in growth trends of a certain components can be detected, thus preventing misleading forecast conclusions. Again, no one approach is consistantly used in the industry, and both are used successfully by different utilities /11/.

2.5.4 SUITABLE APPROACH FOR INDIAN CONDITIONS

Basically, peak load and energy both forecasts are needed for any utility. The energy approach for load forecasting is not suitable under Indian conditions because of low per capita consumption in the country. It is also true that in advanced countries, there is a great degree of saturation in the localities electrified and the customers using power, with the consequence that usually the rate of increase in energy consumption is more predominant than

the rate of growth in customers or electrified localities. In other words, the growth in foreign countries is more due to increased consumption by existing customers rather than by the addition of new customers and consequently the rise will be more predominant in the energy than in the peak load. In India, however, the growth is mainly and predominantly due to new consumers, new localities and new loads rather than to extensions and increased consumptions by existing consumers. With the consequence, the rate of growth is more predominant in the peak load than in the energy. This shows, that the planning of additional generation should be done with reference to the anticipated peak load and not on the energy basis. But it has no bearing on the method to be adopted for working out the anticipated grid peaks for future years. It is, therefore, left to the choice of forecaster as to which approach is to be taken for putting forward a forecast which, in the ultimate analysis, can be in terms of both the energy and the peak load. The energy approach appears to have the definite advantage of minimum number of assumptions and consequently better result and also it will make it easy to project the estimates for the future years, as the recorded energy consumption figures for the past years for the different load categories are available and general data regarding population, number of localities, number of houses etc. are

also available from census report and other statistical publications. These will enable to establish trend, if any, and possible growth to assist in making projections of energy requirements. Requirements of bulk industries can be directly worked out and projected with reference to licensed production capacities and expansion plans. System losses and auxiliaries consumptions can also be worked out correctly in terms of energy from recorded data and projected without assuming any average percentages. It would appear that the load assumption in terms of energy growth will be adequatly informative if broken down into different categories as Domestic, Commercial, Public lighting, Industrial, Irrigation and others.

2.6 BASIC REQUIREMENT FOR REALISTIC FORECASTING

The basic requirements /8/ for a realistic load forecasting irrespective of method used, are the following:-

(i) The statistics of electricity supply and consumption should be reliable.

(ii) Instrumention to record generation, transmission and consumption of electricity should be adequate.

(iii) Trained personnel involved in load forecasting.

2.6.1 STATISTICS

Though the electricity Statistics are being collected and compiled by so many agencies for their own use. Yet the data collected is normally insufficient and unreliable or both. These agencies have their own way and there is no uniform procedure. There is very little check to ensure the correctness of the collected data. There is also much delay in notification of these data.. Therefore, there is an urgent need for rationalising the entire procedure and organisation for data collection. As the power system grows in size, the problem which has to be faced will become more and more complex and hence more detailed and accurate statistics will be needed to solve them.

2.6.2 INSTRUMENTATION

The instrumentation available in most of the power system is also inadequate. To start with, at least all the generating stations and grid sub-station should have the necessary integrating instruments to record energy and power inflows and outflows. Besides special recording instruments, complementary equipments for load studies should also be made available. This, together with proper organisation, will ensure availability of reliable electricity statistics which inturn would make it possible to undertake scientific system studies and make realistic forecasts of power demands.

2.6.3 TRAINING

Considering the amount of work involved, the availability of properly trained persons for forecasting power demand, is totally inadequate. Further, forecasting power requirements within the range of economic practicability is not possible due to inherent errors of load forecasters.

CHAPTER - III

LOAD FORECASTING METHODS

3.1 Forecasting techniques may be subdivided into three broad classes. Techniques may be based on extrapolation or on correlation or on a combination of both. Techniques may be further classified as either deterministic, probabilistic, or stochastic /11/.

3.1.1 EXTRAPOLATION

Extrapolation technique involves fitting trend curves by the method of least squares, to basic historical data adjusted to reflect the growth trend itself. With a trend curve, the forecast is obtained by evaluating the trend curve function at the desired future point. Such a technique is to be classified as a deterministic extrapolation, since no attempt is made to account for random errors in data or in the analytical model.

If the uncertainty of extrapolated results is to be quantified using statistical entities such as means and variance, the basic technique becomes probabilistic extrapolation. The uncertainty arises from two sources: Uncertainty in the historical data and uncertainty in the analytical model chosen to describe the underlying growth in load. With regression analysis, the best estimate of the model, describing the trend can be obtained and used to

forecast the trend.

The use of stochastic models to generate a forecast from random inputs derived from historical data, has been investigated but is not much wide-spread. The inputs to the model, tend to be the random change in the trend component, the random slope of the change in seasonal component and associated weighting factor, and a general noise component. The statistics of all the random inputs plus the weighting factor are determined by matching the statistics of the historical demand data with corresponding statistics for the output of the model. This step can be performed only after a transformation of the basic model and the historical data is made, since the data and untransformed model are non-stationary that is, their statistics are time dependent. With the model matched to fit historical demand data, the forecast is obtained by exciting the transformed model by random inputs whose statistics are known. The resulting time series, after an inverse transformation, is the forecast desired.

3.1.2 CORRELATION

Correlation technique relate system loads to various demographic and economic factors. This approach is advantageous in forcing the forecaster to understand clearly the inter-relationship between load growth patterns and other measureable factors. The most obvious disadvantage,

however, results from the need to forecast demographic and economic factors, which can be more difficult than forecasting system loads. Typically, such factors are population, employment, building permits, appliances saturation, business indicators, weather data, national income etc.

3.2 There are two steps /9/ involved in load forecasting.

(i) The first step is to divide the whole load into components.

(ii) The second step is to forecast the components and then to reconcile them to obtain forecasting of the whole system.

Based on the making use of the past available data, socio economic conditions, probability approach and other related factors, several methods have been developed for estimating the future demand of a system. The following are some of the methods which are being used for load forecasting.

(i) Forecasting on the basis of classwise consumption.

(ii) Forecasting on the basis of mathematical formulae.

(iii) Forecasting on the basis of historical trend.

(iv) Forecasting on the basis of correlationship between development of electricity and development of economic factors.

(v) Method of norms.

(vi) Appliance and appliance group method.

(vii) Forecasting by Probability Approach.

(viii) Load Survey Method..

(ix) Wholesale method of extrapolation and comparison /12/

(x) Input-output Method /13/

(xi) Simplified input-output Method /14/

3.3 CLASSIFICATION AND CHARACTERISTICS OF LOAD

In most of the methods given above, total forecast is obtained by combining forecasts for various classes of customers. Loads may be classified broadly, as residential or domestic, commercial and industrial, and other. Other customers are municipalities or division of state and federal governments using energy for street and highway lighting. In addition, sales to public authorities and to railroads and railways, sales for resale, and interdepartmental sales also come under 'other' classification. Unfortunately for forecasting purposes, these clasifications overlap in the sense that customers in a given class do not have characteristics unique to that class; that is, the classifications are not mutually exclusive. Within the broad

classes mentioned, further sub-divisions may be defined. Residential consumers may be sub-divided into rural, urban and other sub-divisions that may be valuable in some cases.

Perhaps, more useful classifications of customers for forecasting purposes would be made by type of use, level of use, rate schedule, or geographic area. Classification by rate schedule is potentially a viable way to classify consumers, because it tends to lump similar types of customers into the same rate category./11/.

3.3.1 Of the three broad classes of loads, residential loads have the most constant annual growth and the most seasonal fluctuations. The seasonal variations of the residential component in many cases are responsible for the seasonal variations in the system peak. This characteristic is due to the widespread use of weather sensitive devices such as space heaters and air conditioners. Other high energy devices used by residential customers are water heaters, refrigerators, and dryers. Refrigeration loads tend to have constant characteristics as compared to the cyclic load characteristics of dryers and water heaters. Barring a substantial lead forward in solar energy technology in the next decade and the increase in per capita consumption due to increases in weather sensitive residential loads will play an even greater role in determining system load pattern.

Commercial loads are also characterized by seasonal fluctuations, and again the fluctuations are primarily due to the extensive use of air conditioning and space heating. The introduction of new devices - the electric car, rapid transit etc.will certainly influence the characteristics of future load.

Industrial loads are considered base load that contain little weather dependent variation. However, depending on the type of industry, these loads may have unique characteristics because of shift operations etc.

Other loads, may have seasonal fluctuations depending on specific cases. In most instances, however, the growth trend for this classification is considered stable, although this does not mean that it will remain stable.

As saturation level and per capita consumption increase, reflecting wide spread use of weather sensitive devices, the need to include weather effects in forecasting future requirements will become imperative. It is well documented that most system peak demand occur as a direct result of seasonal weather extermes. 'Heat Storms' and 'cold Waves' are terms discribing inclement weather that adversely affects the ability of a utility to meet load requirements.

Besides the tremendous impact of weather on load

growth, other seasonal variations are caused by economic and demographic effects. In heavy industrialised areas many industrial customers are characterised by cyclic variations load requirement due to normal variations in production level. Demographic effects also play a role in establishing load patterns and vary with general migration patterns and other factors. Solar Energy technology may have a tremendous impact on the load pattern now experienced by electric utilities.

3.4 From amongst the methods discussed above, we will discuss in detail only those methods which are commonly used for load forecasting. Rest of the methods are combination or part of these methods.

3.4.1 FORECASTING ON THE BASIS OF CLASSWISE CONSUMPTION /7/

This method is applicable to both short term and long term forecasting. This consists of estimating energy consumption under different classes of load. By summing up the estimated consumption of different classes and adding up the losses, the forecast of total energy required is made. From the energy requirement so worked out, peak load is calculated with the estimated or assumed load factor. Regarding losses, it may be stated that the ratio of industrial deliveries to the total classified use has been an important factor in influencing the losses. Generally the greater is the ratio, the less is the percentage

because less transmission and distribution is involved in delivering power to industrial consumers and usually the delivery voltage is higher. The percentage losses are of course affected by the factors other than concentration of industrial loads e.g. increase in load densities in commercial classes helps in reducing the losses. Usually for forecasting, energy consumption is estimated separately for (i) Domestic and Commercial lighting and small power. (ii) Public lighting. (iii) Water works and Drainage pumping. (iv) L.T. Industries. (v) H.T. Industries with a demand less than 1 M.W. (vi) H.T. Industries with a demand more than 1 M.W. (vii) Irrigation pumping and dewatering. (viii) Railway Traction.

In respect of the items (i) to (v.) projections of consumption are done by taking into account the past trend of growth in the consumption of each class. The observed growth rate during the past 4-5 years are taken as guide-lines for projecting energy consumption for the next 4-5 years. In respect of item (vi) namely H.T. Industries with an individual demand more than 1 M.W., the forecast of energy consumption is done individually for each industry, existing, under construction or likely to be established during the period of forecast. Anticipated consumption of such industries is totalled up to get the consumption under this class. In respect of item (vii) viz.

irrigation and dewatering, the forecasting is done by taking into account, the number of pumpsets/state tubewells targetted for energisation during the survey period and multiplying the same with the average energy consumption per pumpset/ state tubewell, so, as to arrive at total energy consumption. Under this class, energy consumption per pumpset/state tubewell, is assumed by taking into account the rate of energy consumption per pumpset/state tubewell over the past 4-5 years. In respect of item (viii) viz. Railway traction, the energy consumption is based on the programme of electrification of various Railway tracks. To the total energy consumption estimated in the manner already described, losses are added to get the energy requirement. From the energy requirement with the help of estimated load factor, the peak load is determined.

This method is most suitable for planning the electricity supply in undeveloped areas for shorter periods. For longer periods, it tends to give lower values. Another advantage of conducting load survey is its ability to assess the demand areawise which is very essential for planning the distribution and location of sub-stations and their expansions.

3.4.2 FORECASTING ON THE BASIS OF MATHEMATICAL FORMULA

G.B. Scheer /7/ of United States, has developed an excellent mathematical formula requiring the use of population forecast for forecasting the long range power

requirement. The formula has been developed from the thesis that for every 100 fold increase in per capita generation, the rate of growth in generation will be reduced by half. It is an established fact that rate of growth in generation decreases with the increase in per capita generation and the thesis lays down how exactly the reduction is expected to take place. The study of actual cases may reveal this important feature. Taking the cases of India and Sweden where the per capita generation is around 100 kwh and 10000 kwh respectively, it is interesting to note while in India, the growth in generation is around 12% per annum, the same in the case of Sweden with 100 fold increase in per capita generation, is around 6% per annum, justifying the soundness of the thesis. The mathematical formula of Scheer has been checked with regards to its applicability for future forecast in a number of countries in the world including India and the United States and found to be quite satisfactory. Its applicability over a very long term projection, may be questionable but according to the Scheer there appears to be no other method that will give better results.

3.4.2.1 The formula developed by Scheer for estimating generation requirement in utilities is given below:-

$$\text{Log } G = C - 0.15 \text{ Log } U \qquad (3.1)$$

$$\text{or, } G = 10^C/U^{0.15} \qquad (3.2)$$

Where G, is the annual growth in generation in percentage. U is per capita generation. C is constant which is 0.02 times of population growth rate in percentage plus 1.33, and both the logarithms are to the base 10. The constant of 0.15 which is almost 0.150515 (which is 1/2 of log 2), will validate the conclusion that, "a hundred fold increase in per capita generation will reduce the rate of growth by half."

From a starting year for which generation is known, the forecast of generation with the help of Scheer's formula is calculated from year to year basis. Both forward and retrograde calculations may be required. The forward calculations are meant for making future forecast and retrograde one for checking the validity of the formula to enhance the accuracy of the forecast. Special emphasis is laid for the starting year. The starting year has to be such, when there had been consistent load growth.

For starting year, Scheer recommends, taking RMS values of generation over a five year period, two years preceeding and two years succeeding from the starting point instead of actual generation for that year.

For forward calculations, starting year's generation, population and forecast of population of future years are required. To start with, the value of C, and

per capita generation U, for starting year are worked out and then the growth rate G, is determined with the help of formula (3.1) or (3.2) given above.

The generation in the next year is worked out by multiplying the generation in the starting year by (1 + G/100). Generation for the next year being thus known and forecast of population being available, the value of C and U, for the next year are then evaluated and with these values, the growth rate G, for the subsequent years is worked out. Subsequent years generation is then determined with this growth rate. The process is repeated till the year for which the forecast is required, is reached.

For retrograde calculations, Scheer's formula would require to be developed in different form as shown below:-

Let X be the generation in the starting year which is known and Y be the generation in the previous year, which is required to be calculated then.

$$Y(1 + G/100) = X \qquad (3.3)$$

$$\text{or, } Y(1 + 10^{C}/100.0\ U^{0.15}) = X\ ,$$

substituting $10^{C}/U^{0.15}$ for G, from equation (3.2)

$$Y(1 + 10^{C}.P^{0.15}/100.0\ Y^{0.15}) = X\ ,$$

substituting Y/P, for U, where P, is the population in

previous year.

$$Y + 10^{C}.P^{0.15}.Y^{0.85}/100) = X$$

$$\text{or, } Y + KY^{0.85} = X \qquad (3.4)$$

substituting K, for $10^{C}.P^{0.15}/100$

In the above equation since X is known, K can be calculated from the population and its growth rate in the previous year. The equation would then need to be solved for the values of Y, from known values of K and X. This procedure is to be repeated year wise till the year up to which the retrograde calculations are required.

3.4.3 FORECASTING ON THE BASIS OF HISTORICAL TREND

The mathematical approach for drawing trend line, is very useful for predicting load requirement of short range future. But for long range, this may not give accurate forecast if the load growth in future is sudden, rather than being gradual. In such cases, human judgement is better or else, a few future load requirements must be estimated based on experience, rate of growth and probable future requirements.

Electric energy production or requirement grows through the years. Therefore, the mean of their future trend, may be obtained by extrapolating a mathematical curve that has been fitted to the historical values. Any

number of curves can be fitted to the same data and the one which approximately reflects the growth is selected through judgement. Since the equation of the curve would be known, the forecast with the help of equation, which is a function of time could be made for any length of time. The two important assumptions inherent in this approach are (i) The growth process is the same throughout the historical period. (ii) It will remain same over the specified extrapolation period. Both peak load and energy consumption are often used for this purpose but use of latter is most common.

3.4.3.1 The past data, when arranged and plotted with reference to the time factor, is a time series and it represents the movement of a point under the influence of several economic and other factors. A time series reveals certain characteristic movements or variations, some or all of which are present to varying degrees. The characteristic movements of time-series are generally classified into four main types :- (i) Secular trend, (ii) Seasonal variations, (iii) Cyclic variations, (iv) Irregular or random variations.

The statistical method of forecasting is also known as time series analysis. The time series analysis is a technique for categorising and studying movements in a time series data. A statistical analysis of the past movements of such data enables to (i) determine the past and present pattern of these movements in a given time series and

(ii) obtain clues about the future pattern of these movements. These clues will be used as an aid to forecasting.

For medium and long term forecasting purposes, the concept of secular trend is used. The secular trend of time series, represents the smooth long term pattern. For short term forecasting it is necessary to study the seasonal variations.

3.4.3.2 The trend can be described by a time function which averages fluctuations and exhibits a smooth curve. The trend curve is usually obtained by moving average or by fitting a suitable mathematical function by least square method. The least square method is commonly used as, it results in the sum of the squares of deviations, of the actual load points from the curve fitted, being minimum. Some of the useful curves for forecasting, are the following:

(i)	Straight line	$Y = A + BX$
(ii)	Parabola	$Y = A + BX + CX^2$
(iii)	S-curve	$Y = A + BX + CX^2 + DX^3$
(iv)	Exponential	$Y = Ce^{DX}$
(v)	Modified exponential	$Y = A + Ce^{DX}$
(vi)	Logistic	$Y = 1/(A + Ce^{DX})$
(vii)	Log-parabola	$\text{Log } Y = A + BX + CX^2$
(viii)	Gompertz	$\text{Log } Y = A + Ce^{DX}$

(ix) Combination $Y = A + BX + Ce^{DX}$

Where Y, is variable to be fitted, X, is time unit, e, is Naperian Constant and A, B, C and D are parameters to be computed by the method of least square.

3.4.3.3 SELECTION OF TREND CURVES /24/

Any of the curves mentioned in the previous section, can be fitted into the past data but one which is most suitable for the existing conditions & for the system under consideration, isto be selected. It is important to estimate the standard error. This enables us to make the choice of mathematically best fitted curve. A curve with higher standard error becomes less preferable. When curves have similar standard error, the one giving the best fit to recent data, is to be preferred. It is usually found that the closeness of the fit is normally, the same for most of the curves. There will be little to choose between the curves as representation of the actual data. But when the curves are extrapolated, they diverge and even a smaller extrapolation may lead to unacceptably large divergence. Therefore, it is very necessary to limit the choice of the curve to those whose slope characteristic agrees with the actual data. Alternatively, we calculate the forecast by several methods other than trend curve and compare the results obtained with different trend curves and the other methods. The trend curve whose results are some what

similar to the results obtained by other methods should be chosen.

Trend curve projections for future should be taken as an aid to forecasting. The time period upon which the trend curve is based, must be such that the past pattern in series will be relevant to the future. Assumptions concerning probable future events and their effects upon the forecast demand are influential in selecting the final choice of the trend curve. Trend curves and their choices have also been dealt in Appendix - A.

The main objection to this method is that the direct extrapolation of the past data into future is of purely formal mathematical character, which means that the future development of the estimated quantity being regarded as a function of time. Then the future demand of electricity depends solely on the instant of time for which the estimate is made. This is not a correct assumption as, the electricity demand also depends upon socio-economic factors. This can be overcome to a certain extent by proper assumptions with regard to the future, and selecting suitable trend curve by the application of human judgement. The extrapolation of past data is appropriate, when its growth is basically regular and then it can be assumed that the trend will also continue in future. This method yields good results when development of electricity is basically

regular. The approach is very simple and that is why, this method is very common.

3.4.4 FORECASTING ON THE BASIS OF CORRELATIONSHIP BETWEEN DEVELOPMENT OF ELECTRICITY AND DEVELOPMENT OF ECONOMIC FACTORS

This method /7/ is an ideal method of forecasting from known economic factors such as national income, population, industrial production etc., if a sound correlationship is found between these factors and electricity development. Many countries in the world have attempted to establish such correlationship and some of them have been successful also. For example, Belgium uses the formula: $E = (K.M^{0.6}.2^{0.465t})$. Where E, is electricity consumption, M, is index of manufacture of production, t, is time and K, is adjustment factor. In Neitherland, the formula used is : $E_1 = P^3/L^2$. Where E_1, is industrial electricity consumption, P, is industrial production index and L, is manpower index. By using the above formulae, future consumption of electricity of the respective country can be projected to any length of time provided, the economic factors considered in the formulae are known for that length of time.

In our country, no such relationship as indicated above, has been established so far. The studies on the subject that have been carried out by the Power Survey Directorate of C.W. & P.C. (now CEA), are briefly described

below:

"It was considered logical to link electricity development with national income which denotes total activity comprising the development of industry, agriculture, transport trade etc. National income when regressed with all India generation, using double log model future projection made with the resultant equation, gave very high values of generation. It became apparent that this index, apart from being far toovague, was over sensitive because it is affected by wholesale and retail price indices. Further, in India agriculture sector is a major sector of Indian economy accounting for about 50% of the national income but consumed relatively small quantity of electricity (about 10.2% of the total electricity consumption in 1971-72).

Since consumption in industrial sector forms about 70% of the total consumption, it was considered that correlationship would exist between it and the electricity generation. Index of industrial production when regressed with all India generation, using double log model and projection made with resultant equation, also did not give satisfactory results. The reason for this could be that the index of industrial production, which was developed in 1960, has now become less representative in view of structural changes taken place in economy since 1960.

The weightage pattern of various industries with base 1960 (= 100), does not appear to reflect the true states of affairs as far as production index of some of the electricity intensive industries is concerned.

It is quite likely that multiple correlationship may exist between two or more economic factors for which further studies are required."

The accuracy of this method lies in estimating and predicting the economic factors. In using this method, the economic factors are often predicted by extrapolation of the past data. Then the forecast based on this method will not be better in any way, therefore, forecast based on direct statistical method is preferred. When more than one economic factors are correlated with electricity demand, it is necessary to study the correlation amongst the economic factors. This method is suitable for short and medium term forecast.

3.4.5 METHOD OF NORMS

The basic requirements of this method to forecast electric power demand are /15/ : (i) Preparing estimates of volume of production for perspective period, and (ii) Calculating the consumption of electricity by multiplying the production with the average amount of power required per unit of physical production.

The term volume of production implies not only for the magnitude of industrial production but also for quantities of other items; such as agricultural, transport, construction and others in which use of electricity is involved. Consumers are divided into a number of groups for estimating the requirement conveniently such as industry, construction, agriculture, transport including electrified rail transport, municipal and domestic consumptions and others. The output is expressed in the units like kwh/tonne of product, kwh/tonne/km. etc.

Thus the application of this method requires the information regarding complete plan of production for all the branches of economy for perspective year as well the norms of electricity consumption per unit of product for industry, transport, agriculture and others. The information on the subject are only available when the national/state planning boards have prepared their development plans covering various sectors of economy.

The accuracy of this method depends on the accurate estimation of the targets in the plans and norms of consumption to be applied. Since they are worked out on the basis of past statistics and certain assumptions about the future changes in the manufacturing techniques, use of raw material and degree of automation etc., therefore, there is a possibility of some difference

between the actual and the estimated values. This method is very simple to apply and is suitable for long term as well as short term forecasting, for the country as a whole. It has been tried successfully in U.S.S.R. The accuracy of this method is governed by the uncertainties of the nature of future planned development, for example, the importance of development may be switched over from one sector to another or possibility of substitution of one energy to another.

3.4.6 APPLIANCE AND APPLIANCE GROUP METHOD /16/

This method is suitable for forecasting residential sales /10/ of energy or residential loads. It explains the average residential energy use, in terms of uses by the various appliances. The contributions of individual appliances are summed up to obtain the annual average use per customer. Estimate of appliance saturation can be obtained from surveys, census reports or from the manufacturers of products.

In appliance group method, we divide the customers into groups according to ownership of certain appliances. The estimated percentage of customers in each group is multiplied by estimated average use for each group to obtain the contribution to total average use by groups. The sum of estimated contributions from all groups give the total consumption. Some of such type of groups are :

(i) No major appliance, (ii) all cooking range, (iii)range and refrigerator, (iv) Refrigerator only, (v) water heaters only, (vi) refrigerator and water heater, (vii) range and water heater, (viii) refrigerator, range and water heater, (ix) refrigerator, water heater and house heating appliances and (x) all house heating appliances. In India, group (i) may be further sub-divided into electric lighting and minor appliances group. In big cities, water pumps in houses can form a separate group. The pattern of energy consumption is different for each group.

This method has the advantage that due to appliance saturation, the accuracy in forecasting is high, specially when average consumption is needed. The method is good for assessing the residential requirements only.

3.4.7 FORECASTING BY PROBABILITY APPROACH

This is a method of forecasting by components /9/. Variables like the individual load components, population etc. are random variables. Hence instead of assuming a fixed value for them in each year, they are assumed to have normal distribution around their mean. The operations are similar except for their probabilistic nature. That is, each operation manipulates the entire probability distribution rather than single value. A probability distribution of the load for a future year is obtained by multiplying the probability distribution of number of customers for that

year and the corresponding year's probability distribution of load per customer. The adoption of this approach essentially requires the use of high speed digital computer as the computations involved are large.

The approach involves isolating and separating the historical data into desired components in order to establish trends to be used in forecasting future loads. Some of the factors considered for the analysis of components are : (i) Population of the service area, (ii) monthly kwh use per residential customers, (iii) industrial hours use of billed demand and (iv) an index of business level.

It is necessary to separate out the energy components of weather sensitive cooling and weather sensitive heating loads from the total system load. This can be done by regression analysis using digital computer. This has been dealt in section 3.5.2 briefly. The component forecasts are obtained by analysing and extrapolating the historical trend data by establishing a trend curve, which is best fit curve coupled with human judgement. The forecast values of each component are not a single valued figures. For each year, each of the component forecasts is expressed by two variables mean and variance which define a complete probability distribution. All the components are treated as subject to random variations and probability distribution assumed is, Gaussian or normal distribution.

In probability approach, each manipulation like adding, multiplying etc. will take the entire probability distribution rather than single values.

The problem of individual forecasts is solved in the following stages :

I. Prepare component forecasts (like population, per capita load component etc.) by converting the available data into mean and variance for each year of the forecast period. The choice of variance depends on human judgement.

II. Perform the forecasting process. For example, the residential load for a particular month is forecasted in the following manner. Using the data of residential load per customer every year, obtain the prediction by known method. This gives the mean of the residential load per customer. Similarly predict the mean for population for that year. Choose proper variances and covariances. Here, the uncertainty factors like population change, famine, foreign exchange conditions and mansoon conditions are taken care of in the choice of variance. Covariance terms determine the way in which the factors are linked. If population is on increase, per capita consumption increases and so, the covariance between them is positive. If

it does not effect the consumption, the covariance is zero. Once the population and load are predicted, they are multiplied using probability multiplication methods.

III. Express the result in a simplified manner by converting means and covariances into probability.

IV. Analyse the forecast in order to determine its sensitivity to change in original data.

Solution to probability approach essentially lies with the application of human judgement apart from the facilities provided by the digital computer. Proper judgement is necessary in expressing the variance of each component forecast.

3.4.8 FIELD SURVEY METHOD

In this method, the survey parties /18/ visit each and every town and village of the area under investigation to ascertain and record the existing and future power demands. The data regarding present and future needs of power is collected and compiled, grouping all the consumers in a few categories /19/ of load which are identical in nature, namely : Domestic or residential, commercial light and small power, street lighting, industrial power, irrigation, traction and water supply and drainage. Having thus obtained a picture of present conditions alongwith a knowledge of future requirements, the surveyor tries to

evolve a pattern of load growth by taking into account all the probable influences and changes that are likely to take place under various categories of loads.

The method is most suitable for assessing the immediate demand of power of a locality or region for planning the distribution system and location of sub-station and their expansion etc. This method of load forecasting is however not adequate for long term assessment of power requirement of a state or a country as a whole, particularly the one which is undergoing a process of planned development. This gives better results for short term forecast and tends to give lower values for longer periods. Load survey is one of the costliest method and hence before starting this, proper planning should be done including man power and their competency.

3.5 FORECASTING PRACTICES OF A VERY SHORT DURATION

Mathematical models have been developed for hour to hour and minute to minute forecasting to solve operational and other problems related with very short duration forecasting. Basic approach and technique for most of these models are either based on trend method, mathematical formula and correlation method or combination of these. As we are not concerned with short range forecasting of load, so we will discuss in brief, a representative method.

3.5.1 PEAK DEMAND FORECASTING - A REPRESENTATIVE METHOD /11/

Some well defined analytical methods have been developed over last few years to aid the forecaster in determining accurate peak demand. As the peak demand is dependent on weather conditions, this approach to forecast peak load include also wheather conditions. Modern practice in most of the advanced countries is to adopt weekly peak demand forecasting as opposed to monthly or annual forecasting. The difference is in the amount of historical data available, that is, the data sampling rate. Given weekly peak demand forecasts, one can find straightway monthly or annual forecast. The basic approach is as follows /11/ :

I. Determine seasonal weather load model.

II. Separate historical weather sensitive and non-weather sensitive components of weekly peak demand using weather load model.

III. Forecast mean and variance of non-weather-sensitive component demand.

IV. Extrapolate weather load model, and forecast mean and variance of weather-sensitive component.

V. Determine mean, variance and density function of total weekly forecast.

VI. Calculate density function of monthly or annual forecast.

It can be safely assumed that the seasonal variations of peak demand are primarily due to weather. If not, then before step-III, any additional seasonal variation remaining after weather sensitive variations are removed, must also be removed. Several methods have been successfully exployed to remove such seasonal variations. This approach needs, a data base of at least 12 years in addition it also requires to develop the weather load models, daily peaks and coincident weather variable values.

3.5.2 WEATHER LOAD MODEL

To determine the weather load model based on historical data, it is common to plot a scatter diagram of daily peaks versus an appropriate weather variable or variables. Although there are many variables to choose from, dry-bulb temperature and humidity are considered important. For simplicity only dry-bulb temperature is used as weather variable. Thus, the scatter diagram from which the load model is obtained will be as shown in figure-3.1. Using linear regression analysis or curve fitting techniques, three straight line segments can be defined and used to describe the model: that is,

$$w = k_s(T - T_s) \qquad \text{if} \quad T > T_s \tag{3.5}$$

$$= -k_w(T - T_w) \qquad \text{if} \quad T < T_w \tag{3.6}$$

$$= 0 \qquad \text{if} \quad T_w \leqslant T \leqslant T_s \tag{3.7}$$

The parameters of the model are the slopes k_s and k_w and the thresold temperatures T_s and T_w.

With the weather load model known, the weather sensitive component of weekly peak demand data can be calculated. Knowing the weekly peak coincident dry-bulb temperatures and this component can be subtracted from the historical data to obtain the non-weather sensitive component of peak demand. The non-weather component is used in step-III, to forecast the mean and the variance of the non-weather sensitive component of future weekly peak demands. Detailed description of forecasting two components have been dealt in /11/.

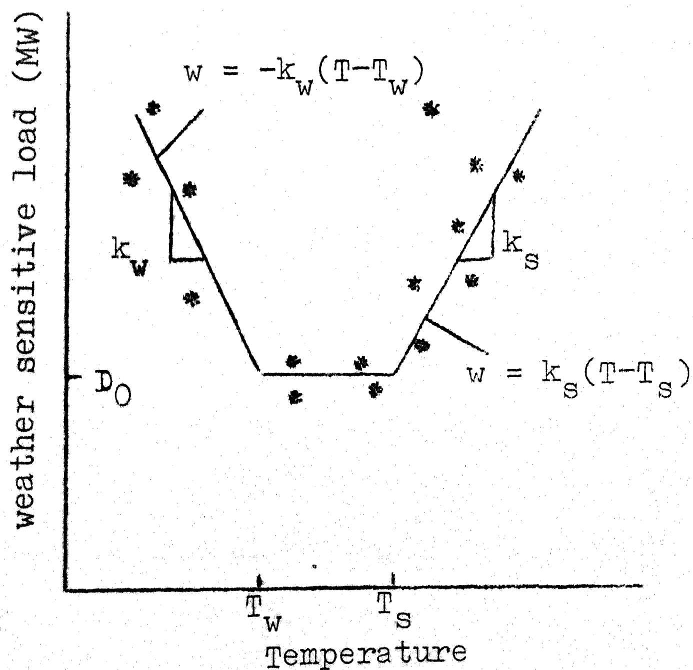

Figure: 3.1 Weather load model

CHAPTER - IV

LOAD FORECASTING OF U.P. POWER SYSTEM - LONG AND MEDIUM TERM

4.1 Some of the methods of the forecasting which were discussed in the previous chapter, are put to use in this chapter, for the load forecasting of U.P. Power System, for the years 1983-84, 1988-89 and 1993-94. Study based on long and medium range of forecasting have been done, in view of long term planning of Uttar Pradesh State Electricity Board (UPSEB). The figures for load factor, transmission and distribution losses as percentage of total energy utilised, auxiliary consumption etc. have been assumed after consultation and discussion with the planning wing of UPSEB. All the data utilised, have been taken from UPSEB statistical report and publication of U.P. Govt. Planning Department.

4.2 CALCULATION OF U.P. POWER REQUIREMENT BY SCHEER'S FORMULA

For the calculation of power requirement by Scheer's formula /7/, the starting year considered in the study is 1970-71, when load growth in U.P. was more or less consistent. The RMS value of generation for 1970-71 of 4891 MU, was determined from the generation in the years 1968-69, 69-70, 70-71, 71-72 and 1972-73. From the starting year 1970-71, calculations have been made upto the year 1993-94.

The growth of population in U.P. from 1970-71 to 1993-94, which is needed for calculations, given in table-4.1.

Table-4.1 : Growth of population in U.P.

Year	Population (Millions)	Year	Population (Millions)
1970-71	88.341 (Actual)	1982-83	109.588
71-72	89.8	83-84	112.0
72-73	91.4	84-85	113.568
73-74	93.0	85-86	115.158
74-75	94.8	86-87	116.77
75-76	96.5	87-88	118.405
76-77	98.2	88-89	120.0
77-78	100.0	89-90	121.68
78-79	102.0	90-91	123.384
79-80	103.846	91-92	125.111
80-81	105.726	92-93	126.863
81-82	107.64	93-94	128.639

Population figures upto 1978-79 have been taken from the report of population projection worked out by State Planning Department. From 1979-80 to 1983-84 and from 1984-85 to 1993-94, a uniform population growth of 1.81% and 1.4% have been assumed respectively as indicated in the report.

The calculated and actual values of generation from 1970-71 to 1993-94, in U.P. have been given in table-4.2 and plotted in figure -4.1. From the generation, the requirement of power station auxiliaries is to be deducted

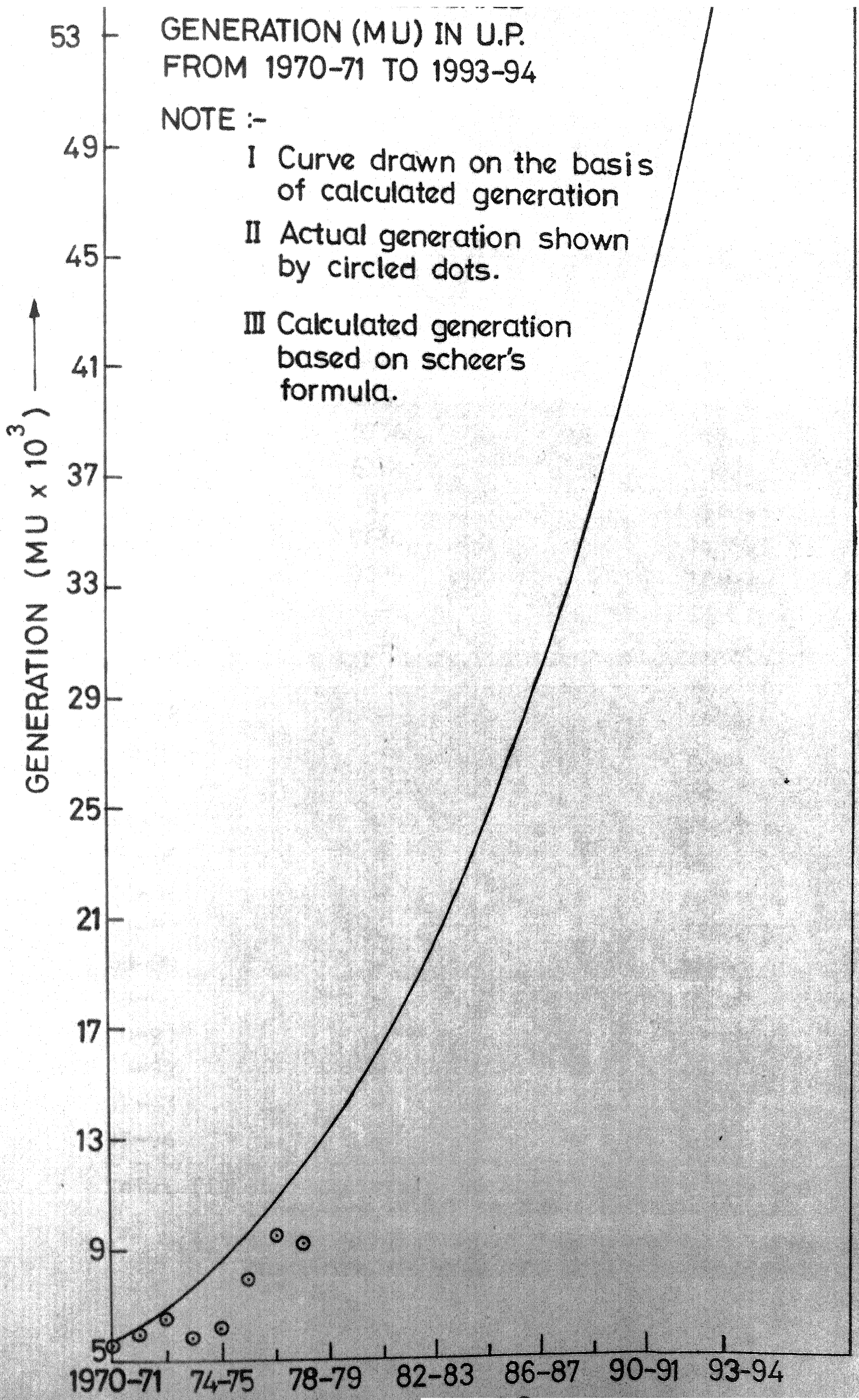
GENERATION (MU) IN U.P.
FROM 1970-71 TO 1993-94
NOTE :-
I Curve drawn on the basis of calculated generation
II Actual generation shown by circled dots.
III Calculated generation based on scheer's formula.
GENERATION (MU x 10^3)
53
49
45
41
37
33
29
25
21
17
13
9
5
1970-71
74-75
78-79
82-83
86-87
90-91
93-94

Table-4.2 : Actual and calculated generation (Scheer's formula)

Year	Actual generation (MU)	Calculated generation (MU)
1970-71	5529	5489*
71-72	5986	6170
72-73	6559	6929
73-74	5736	7768
74-75	6154	8703
75-76	8013	9729
76-77	9630	10858
77-78	9289	12105
78-79	-	13488
79-80	-	14994
80-81	-	16647
81-82	-	18458
82-83	-	20440
83-84	-	22648
84-85	-	24977
85-86	-	27513
86-87	-	30272
87-88	-	33272
88-89	-	36520
89-90	-	40052
90-91	-	43881
91-92	-	48027
92-93	-	52513
93-94	-	57363

Note: (i) The electricity generated by Renusagar and licensees is not included in above table.

(ii) *- RMS value derived from actual generation in the years 1968-69, 69-70, 70-71, 71-72 and 1972-73.

to get the energy requirement at the generating station bus-bars. The consumption in power station auxiliaries in U.P. Power System, form about 6% to 7% of total generation, from 1970-71 to 1977-78. It may increase to 7.5%, 8.0% and 8.5% in 1983-84, 1988-89 and in 1993-94 respectively due to anticipated large scale addition in the thermal capacity. To arrive at peak load, we have to assume appropriate value of load factor. The overall annual load factor of U.P. Power System is assumed to be 60% for the entire period from 1978-79 to 1993-94.

4.2.1 SCHEER'S FORMULA (SAMPLE CALCULATION)

$G = 10^{C}/U^{0.15}$, where G = % annual growth in generation, U = per capita generation, C = (0.02X% population growth rate) + 1.33.

Base year = 1970-71. Generation in MU

1968-69 = 4371, 69-70 = 4701, 70-71 = 5529, 71-72 = 5986 and 1972-73 = 6559.

RMS value of generation in 1970-71

$$= \sqrt{\frac{(4371)^2 + (4701)^2 + (5529)^2 + (5986)^2 + (6559)^2}{5}}$$

= 5489 MU

To arrive at 1971-72 estimates:

population in 1971-72 = 89.8 million

population in 1970-71 = 88.341 million

$\%$ growth in population = 1.81%

$C = 0.02 \times 1.81 + 1.33 = 1.366$

$U = 5489/88.341 = 62.13$ kwh

$G = (10)^{1.366}/(62.13)^{0.15}$

$\text{Log } G = 1.366\log 10 - 0.15\log 62.13 = 1.094$

$G = \text{Antilog}(1.094) = 12.42\%$

Generation forecast for the year 1971-72

$= 5489 + (12.42 \times 5489)/100 = 6170$ MU

Based on the percentage consumption of the auxiliaries as indicated and assumed load factor the energy requirement and peak load for the years 1983-84, 1988-89 and 1993-94 are worked out below:

	1983-84	1988-89	1993-94
(i) Forecasted generation (MU)	22648	36520	57363
(ii) Power station auxiliaries consumption (MU) at the rate of 7.5%, 8.0% and 8.5% in the years 1983-84, 1988-89 and 1993-94 respectively.	1699	2922	4876
(iii) Energy requirement (MU)	20949	33598	52487
(iv) Annual load factor	60%	60%	60%
(v) Peak load (MW)	3986	6392	9986

4.3 CALCULATION OF U.P. POWER REQUIREMENT ON THE BASIS OF CORRELATIONSHIP BETWEEN ELECTRICITY CONSUMPTION AND DEVELOPMENT OF ECONOMIC FACTORS (REGRESSION METHOD)

It is an established fact that per capita total

energy consumption of any country/state, which is very much correlated to the per capita income, is regarded as one of the basic index for the overall economic development. The electricity is one of the most important form of the commercial source of energy and its per capita consumption also serves a very good index of industrial development, standard of living and other economic developmental concepts.

The other way of forecasting the energy requirement could be, by correlating the dependent variable (total electricity utilisation) with independent variable/variables (economic factors), using time series data (refers to a sequence of measurements moving through time) and projecting it for future years. This method of forecasting is normally termed as Regression Method of forecasting. In this section an effort has been made for evaluating future demand of electricity in U.P., by correlating electricity utilisation with total state income, population and time period, for the years 1983-84, 1988-89 and 1993-94, using some linear regression models (Appendix-B).

The data regarding total utilisation of electricity in U.P., total state income (on 1960-61 firm prices) and total population of state from 1968-69 to 1993-94 are given in table-4.3. This table also includes the time period in years taking 1968-69 as the first year. Linear regression models have been envisaged using time series

variable - Y) is a function of the independent variables: (i) total state income on firm prices of 1960-61 (X_1), (ii) total population of state (X_2) and (iii) time period (X_3), taking 1968-69 as first year.

The income of the state (on fixed prices) has been taken as an independent variable. Although the income distribution pattern might have some impact onelectricity utilisation in domestic sector, this has not been considered in the present study. The state income figures for the period 1968-69 to 1974-75, are same as reported by the U.P. Govt. in its publication on growth of state income. The annual rate of growth of state income has been envisaged as 4.5% during fifth plan (1974-75 to 1978-79), and 5% during sixth plan (1979-80 to 1983-84). However, for the future, it has been presumed that annual compounded rate of growth of state income (on 1960-61 firm prices) shall be 5.5% and 6% during seventh (1984-85 to 1988-89) and eighth (1989-90 to 1993-94) five year plans respectively.

Another independent variable is total population of state. The urban-rural ratio of population might play some role in the overall electricity utilisation in the state, but this aspect has been neglected here. The state has envisaged a population growth rate of 1.81%, compunded annually upto end of the sixth plan (1983-84). Beyond 1983-84, the population growth rate has been anticipated

to fall sharply to the level of 1.4% during the seventh and eighth plans.

The pasage of time also affects the utilisation of electricity. The use of electricity, which at one time used to be a matter of luxury (atleast in domestic sector) is more and more becoming a matter of necessity. In U.P., the electricity utilisation is still at its thresold and with the passage of time, electricity will be replacing in more and more areas, other conventional source of energy.

4.3.1 Before choosing suitable model to project electricity utilisation, the following linear regression models by taking different combinations of X_1, X_2 and X_3 , have been tested, using multiple linear regression program (section-4.6 and Appendix-B).

(a) $\text{Log } Y = A_0+A_1\text{Log } X_1+A_2\text{Log}X_2+A_3\text{Log}X_3$

(b) $Y = A_0+A_1X_1+A_2X_2+A_3X_3$

(c) $Y = A_0+A_1X_1+A_2X_2+A_3X_3+A_4X_1^2$

(d) $Y = A_0+ A_1X_1+A_2X_2+A_3X_3+A_4X_2^2$

(e) $Y = A_0+A_1X_1+A_2X_2+A_3X_3+A_4X_1X_2$

(f) $Y = A_0+A_1X_1+A_2X_2+A_3X_3+A_4X_1^2+A_5X_1X_2$

(g) $Y = A_0+A_1X_1+A_2X_2+A_3X_3+A_4X_2^2+A_5X_1X_2$

(h) $Y = A_0+A_1X_1+A_2X_2+A_3X_3+A_4X_1^2+A_5X_2^2$

(i) $Y = A_0+A_1X_1+A_2X_2+A_3X_3+A_4X_1^2+A_5X_2^2+A_6X_1X_2$

The computed values of coefficients A_0, A_1, A_2, A_3, A_4, A_5 and A_6 are given in table-4.4. These values have been computed using above referred, multiple linear regression program by least square method. To check the validity of models, the value of least square objective function S and multiple correction factor R^2 have also been computed in each case and are given in table-4.4.

Using each of above regression models, the values of electricity utilisation have been computed starting from the year 1968-69 to 1993-94. The actual and computed values of electricity utilisation, using above regression models are given in table-4.5.

From table-4.5, it can be seen that model-(f) and (i), yield negative values when projected for future years. Therefore, model-(f) and (i) may be dropped here safely. For other models, electricity utilisation from the year 1978-79 to 1993-94 have been plotted in figure-4.2.

Visual examination of the curves drawn in figure-4.2, reveal that models-(b), (d) and (e) do not represent conditions in a developing state like U.P., as they do not show a growth rate of compunded type for electrical energy utilisation. Moreover, regarding validity of model, the values of S and R^2 should be 0 and 1 respectively, correspon-ding to a perfect fit. From table-4.4, it can be seen that

Table-4.4 : Computed values of coefficients, S and R^2 (Regression model 1)

Regression model	A_0	A_1	A_2	A_3	A_4	A_5	A_6	S	R^2
(a)	-22.27843	1.43391	3.63172	-0.11599	-	-	-	1333636	0.93458
(b)	-116261.64	0.24607	1366.6986	-2020.1557	-	-	-	1373651	0.91602
(c)	-31395.573	-0.67473	481.99031	-602.32907	0.00002	-	-	1334443	0.91842
(d)	39205.914	0.26786	-1103.3621	-174.14191	7.2481	-	-	1345552	0.91774
(e)	38048.532	-1.20875	-455.33421	258.57913	0.01632	-	-	1391857	0.91102
(f)	299751.45	-2.11407	-5064.1101	1993.3298	-0.00025	0.1601	-	1078327	0.93408
(g)	-293748.14	-5.03659	6428.8251	-2537.6716	-33.894	0.0581	-	1213685	0.92580
(h)	-46579.226	-0.79094	779.9389	-732.448	0.00002	-1.1919	-	1334268	0.91843
(i)	-488954.96	-16.3362	12373.326	-5265.3359	-0.00057	-115.46	0.49	531270	0.96752

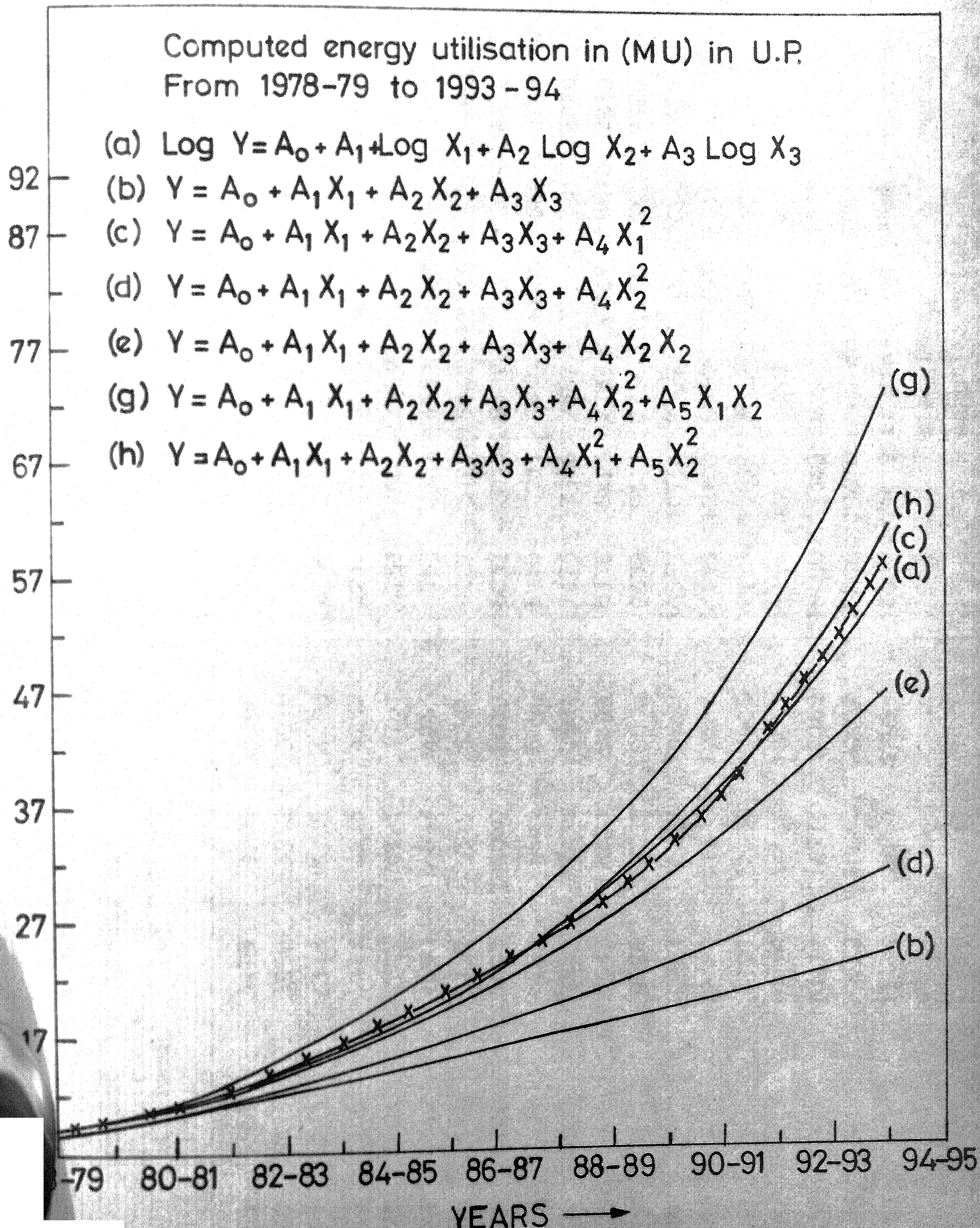
Computed energy utilisation in (MU) in U.P.
From 1978-79 to 1993-94
(a) $\log Y = A_0 + A_1 + \log X_1 + A_2 \log X_2 + A_3 \log X_3$
(b) $Y = A_0 + A_1 X_1 + A_2 X_2 + A_3 X_3$
(c) $Y = A_0 + A_1 X_1 + A_2 X_2 + A_3 X_3 + A_4 X_1^2$
(d) $Y = A_0 + A_1 X_1 + A_2 X_2 + A_3 X_3 + A_4 X_2^2$
(e) $Y = A_0 + A_1 X_1 + A_2 X_2 + A_3 X_3 + A_4 X_2 X_2$
(g) $Y = A_0 + A_1 X_1 + A_2 X_2 + A_3 X_3 + A_4 X_2^2 + A_5 X_1 X_2$
(h) $Y = A_0 + A_1 X_1 + A_2 X_2 + A_3 X_3 + A_4 X_1^2 + A_5 X_2^2$
(g)
(h)
(c)
(a)
(e)
(d)
(b)
92
87
77
67
57
47
37
27
17
-79
80-81
82-83
84-85
86-87
88-89
90-91
92-93
94-95
YEARS →

FIG. 4.2

Table-4.5 : Actual and computed electricity utilisation (Regression model)

Year	Actual electricity utilised (MU)	Electricity utilisation (MU) computed using Regression model (a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)
1968-69	3563	3475	3304	3362	3339	3386	3359	3432	3363	3483
69-70	3715	3950	3942	3918	3984	3939	4215	3734	3908	3878
70-71	4293	4318	4486	4403	4386	4339	4113	4427	4409	4118
71-72	4486	4177	4213	4252	4218	4264	4216	4371	4255	4518
72-73	4804	4709	4721	4781	4751	4804	4762	4873	4783	4945
73-74	4342	4690	4693	4735	4739	4744	4651	4661	4733	4247
74-75	4949	5157	5315	5201	5227	5147	5142	5126	5201	5067
75-76	6346	6008	6080	6019	6037	6011	6192	6035	6019	6510
76-77	7432	6725	6681	6696	6710	6717	6850	6674	6693	6873
77-78	6937	7559	7432	7501	7475	7516	7367	7533	7502	7228
78-79	-	8557	8471	8497	8376	8425	7735	8747	8510	7910
79-80	-	9696	9351	9600	9330	9511	7766	10019	9628	7189
80-81	-	10997	10297	10858	10369	10734	7397	11515	10908	5675
81-82	-	12480	11308	12287	11496	12103	6530	13261	12368	3175
82-83	-	14171	12388	13906	12716	13633	5052	15288	14029	Now
83-84	-	16326	14123	15943	14254	15415	3350	18112	16135	onwards
84-85	-	18412	14776	17968	15490	17349	Now	20598	18230	it starts
85-86	-	20772	15488	20299	16806	19478	onwards	23532	20659	giving
86-87	-	23444	16261	22975	18205	21819	it sta-	26959	23464	negative
							rts giving			values.
							negative values.			

Contd.

Year	Actual electricity utilised (MU)	Electricity utilisation (MU) computed using Regression model								
		(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)
1987-88	-	26468	17097	26039	19692	24388	-	30930	26692	-
88-89	-	29833	17914	29507	21229	27182	-	35419	30365	-
89-90	-	33929	18945	33853	22966	30464	-	41160	34998	-
90-91	-	38597	20055	38854	24811	34073	-	47736	40352	-
91-92	-	43916	21244	44597	26766	38038	-	55229	46523	-
92-93	-	49980	22519	51181	28838	42392	-	63736	53623	-
93-94	-	56888	23880	58717	31032	47165	-	73354	61775	-

values of S is more and R^2 is less for models-(b), (d) and (e) compared to models-(a), (c), (g) and (h). Comparing the values of S and R^2, model-(a) & (g) are a better fit than model-(c) and (h). Therefore, we select the models-(a) and (g) to project the energy requirement.

Now to calculate the energy requirement, transmission and distribution losses (T & D) are to be added in computed electricity utilisation. Transmission and distribution losses as a percentage of total electricity utilised, for U.P. Power System, varies between 25% to 31% for the last 4 to 5 years. It has increased to 31% in 1976-77 from 29% in 1974-75. This may be due to the laying of extensive L.T. network for the purpose of energisation of pump sets and rural electrification. Again this value have gone down to 25% in 1977-78. As larger percentage of T & D losses consist of distribution loss, and state is envisaging intensive energisation of rural areas, this value has been assumed as 26% for the entire period beyond 1877-78 to 1993-94. Thus taking T & D losses as 26% of electricity utilisation, the energy requirement and peak load (assuming overall load factor of the system as 60%) for the years 1983-83, 1988-89 and 1993-94 are worked out and given in table-4.6.

Comparing the above results, with the results of Scheer's formula, the results yielded by model-(g) are on

higher side and the result yielded by model-(a) are much nearer to the results yielded by Scheer's formula. Therefore, we select the model-(a) as a best fit and results yielded by model-(a) are acceptable.

Table-4.6 : Total energy requirement and peak load (Regression model)

Regression model	Year	Electricity utilisation (MU)	T & D losses @ 26% of electricity utilisation (MU)	Total energy requirement (MU)	Peak load (MW)
(a)	1983-84	16326	4245	20571	3914
	1988-89	29833	7757	37590	7152
	1993-94	56888	14791	71679	13638
(g)	1983-84	18112	4709	22821	4342
	1988-89	35419	9209	44628	8491
	1993-94	73354	19072	92426	17585

4.4 CALCULATION OF U.P. POWER REQUIREMENT BY HISTORICAL TREND METHOD

For making long term forecast with the help of this method, some of the curves explained in Appendix-A, have been fitted to the energy requirement (which has been taken as net generation excluding auxiliary consumption) from the year 1968-69 to 1977-78 as given in table-4.7.

The curves have been fitted by the method of

least square, using computer programs (section-4.6). The curves fitted, their equations, computed values of coefficients and sum of squares of deviation in each case are given in table-4.8.

Table-4.7 : Actual energy requirement

Year	Actual energy requirement (MU)
1968-69	4107
69-70	4401
70-71	5198
71-72	5632
72-73	6196
73-74	5374
74-75	5689
75-76	7472
76-77	9023
1977-78	8611

Note: This table do not include the electricity generated by Renusagar and licensees.

With the help of equations given in table-4.8, values of energy requirement for each curve from the year 1968-69 to 1993-94 have been computed and given in table-4.9. The actual and computed energy requirement have been plotted in figure-4.3.

Visual examination of the curves drawn in figure-4.3, reveale that curves-(a) and (e) do not represent the conditions in a developing state like U.P. i.e., the rate of growth in demand is not compounded type.

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Visual examination of the curves drawn in figure-4.3, reveale that curves-(a) and (e) do not represent the conditions in a developing state like U.P. i.e., the rate of growth in demand is not compounded type.

Table-4.8 : Curves fitted and computed values of coefficients.

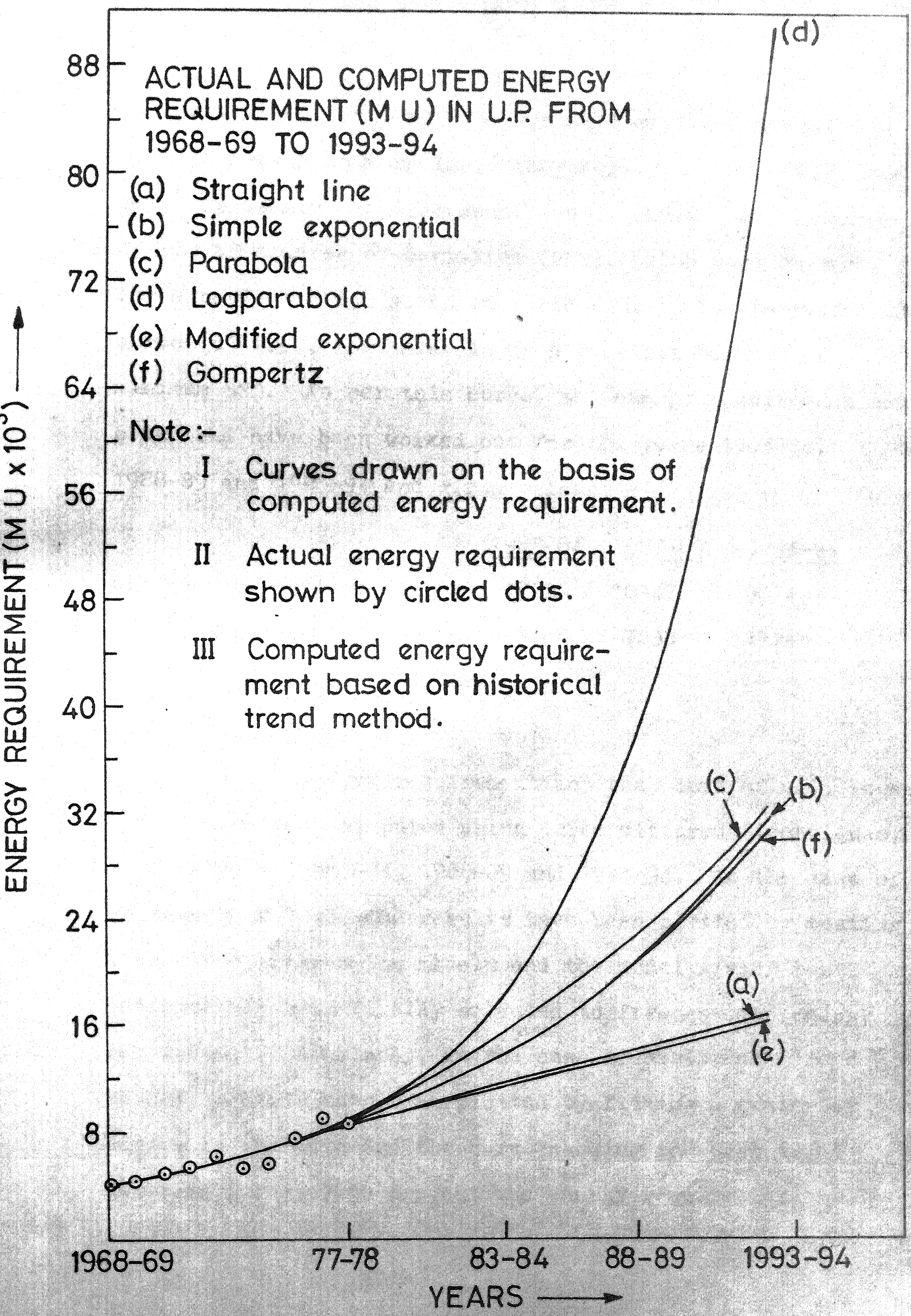
Curve fitted	Equation	Values of coefficients and sum of squares of deviation (SSD)				
		A	B	C	R	SSD
(a) Straight line	$Y=A+BX$	3383.56	506.68	-	-	4094956
(b) Simple exponential	$LogY=A+BX$	3.583	0.035	-	-	3474723
(c) Parabola	$Y=A+BX+CX^2$	4237.31	79.808	38.806	-	3299804
(d) Log parabola	$LogY=A+BX+CX^2$	3.607	0.023	0.001	-	3221347
(e) Modified exponential	$Y=A+B(R)^X$	216987.72	-213616.97	-	0.9976	4120064
(f) Gompertz	$LogY=A+B(R)^X$	33.1767	-29.5948	-	0.9988	3478206

Table-4.9 : Actual and computed energy requirement (Historical Trend Method)

Year	Actual energy requirement (MU)	Computed energy requirement (MU) by fitting curve					
		Straight line	Simple exponential	Parabola	Log-parabola	Modified exponential	Gompertz
1968-69	4107	3890	4154	4356	4284	3883	4150
69-70	4401	4397	4506	4552	4552	4395	4504
70-71	5198	4904	4887	4826	4862	4905	4886
71-72	5632	5410	5300	5177	5219	5414	5301
72-73	6196	5917	5748	5607	5631	5922	5751
73-74	5374	6424	6234	6113	6108	6428	6238
74-75	5689	6930	6761	6697	6658	6934	6766
75-76	7472	3437	7333	7359	7295	7438	7337
76-77	9023	7944	7952	8099	8035	7941	7956
77-78	8611	8450	8625	8916	8894	8443	8627
78-79	-	8957	9354	9811	9896	8943	9353
79-80	-	9464	10145	10783	11068	9442	10139
80-81	-	9970	11003	11833	12442	9940	10990
81-82	-	10477	11933	12961	14058	10437	11912
82-83	-	10984	12942	14166	15966	10933	12909
83-84	-	11490	14036	15449	18225	11428	13989
84-85	-	11997	15223	16809	20911	11921	15158
85-86	-	12504	16510	18247	24117	12413	16422

Contd.

Year	Actual energy requirement (MU)	Computed energy requirement (MU) by fitting curve					
		Straight line	Simple exponential	Parabola	Log-parabola	Modified exponential	Gompertz
1986-87	-	13010	17906	19763	27956	12904	17791
87-88	-	13517	19420	21356	32573	13394	19272
88-89	-	14024	21062	23027	38147	13883	20873
89-90	-	14531	22842	24775	44905	14370	22606
90-91	-	15037	24774	26601	53131	14856	24481
91-92	-	15544	26868	28505	63186	15341	26508
92-93	-	16051	29140	30487	75530	15825	28700
93-94	-	16557	31604	32545	90749	16308	31071



ACTUAL AND COMPUTED ENERGY REQUIREMENT (M U) IN U.P. FROM 1968-69 TO 1993-94
(a) Straight line
(b) Simple exponential
(c) Parabola
(d) Logparabola
(e) Modified exponential
(f) Gompertz
Note :-
I Curves drawn on the basis of computed energy requirement.
II Actual energy requirement shown by circled dots.
III Computed energy requirement based on historical trend method.
ENERGY REQUIREMENT (M U x 10^3)
88
80
72
64
56
48
40
32
24
16
8
(a)
(b)
(c)
(d)
(e)
(f)
1968-69
77-78
83-84
88-89
1993-94
YEARS

FIG. 4.3

The curves-(b), (c) and (f), reveal that the compounded rate of growth is very low. Therefore, the curve-(d), may only represents the true conditions. Comparing the values of sum of squares of deviation (SSD),(which must be zero for a perfect fit), given in table-4.8, it is observed that curve-(d) i.e., Log parabola is a best fit because of minimum SSD. As per this curve, the energy requirement and peak load have been worked out for the years 1983-84, 1988-89 and 1993-94 and given below:

	1983-84	1988-89	1993-94
(i) Energy requirement (MU)	18225	38147	90749
(ii) Peak load (MW), taking 60% overall annual load factor	3468	7258	17266

4.5 The energy requirement and peak load of U.P. Power system have been computed using three different techniques, for the years 1983-84, 1988-89 and 1993-94. In the case of Regression Method, the results have been plotted by testing a number of regression models and the model giving best estimate has been finally selected to forecast the energy requirement. Similarly, in the case of Historical Trend Method, results have been plotted by fitting a number of curves in the data and the curve showing the best trend has been selected to project the energy requirement.

4.6 LISTING OF PROGRAMS

```
C     ************************************************************
C      PROGRAM-1:CURVE FITTING-STRAIGHT LINE AND EXPONENTIAL
C     ************************************************************
C      STRAIGHT LINE(Y=A+B*T),EXPONENTIAL(LOG(Y)=A+B*T)
       DIMENSION Y(40),T(40),YC(40),YL(40),XY(40)
       KL=1
   51  READ1,N
C      N      TOTAL NO. OF YEARS
    1  FORMAT(2I5)
       PRINT1,KL
       PRINT5,N
    5  FORMAT(/5X,'TOTAL NO.OF YEARS=',I5)
       XN=N
       READ2,(T(J),Y(J),J=1,N)
C      T ----- IS YEARS FROM 1 TO NAND Y--- ISDEMAND YEARWISE
    2  FORMAT(6F10.3)
       PRINT6
    6  FORMAT(/5X,'YEARS',5X,'ENERGY DEMAND'/5X,5(1H-),5X,14(1H-))
       PRINT8,(T(J),Y(J),J=1,N)
    8  FORMAT(5X,2(5X,F10.3))
       L=1
       PRINT1,L
       GO TO 7
   30  DO10 J=1,N
       YL(J)=Y(J)
   10  Y(J)=ALOG(Y(J))*0.43429
C      CALCULATION OF COEFFS. A AND B
    7  SY=0.0
       ST=0.0
        ST2=0.0
       STY=0.0
       DO 3 J=1,N
       SY=SY+Y(J)
        ST=ST+T(J)
       ST2=ST2+T(J)*T(J)
    3  STY=STY+T(J)*Y(J)
       A1=SY*ST2-ST*STY
       A2=XN*ST2-ST*ST
        B1=XN*STY-SY*ST
       A=A1/A2
       B=B1/A2
       PRINT9,A,B
    9  FORMAT(/5X,'THE COEFFS. A AND B ARE=',2X,2(5X,F10.3))
C      CALCULATION OF E FORECASTED AND SUM OF SQUARED RESIDUALS
       DSE=0.0
       DSEE=0.0
C      NTEN   REPRESENTED  22 YEARS BEYOND N
       NTEN=N+22
       DO 20 I=1,NTEN
       TI=I
       YC(I)=A+B*TI
C       YC --- REPRESENTS FORECASTED VALUES IN THE CASE OF (ST.LINE
       IF(I-N) 21,21,25
   21  GO TO (24,23),L
   23  BM=Y(I)-YC(I)
C      BM --- REPRESENTS DIFFERENCE BETWEEN ACTUAL Y(I) AND FORECAS
C      YC(I) VALUES OR RESIDUALS IN CASE OF  ST. LINE
```

```
      YX=2.303*YC(I)
      XY(I)=EXP(XX)
C     XY(I) === REPRESENTS FORECASTED VALUES IN THE CASE OF -- STM
      BM=BM*BM
      CM=YL(I)-XY(I)
C     CM === REPRESENTS RESIDUALS IN CASE OF // SIMPLE EXPO.
      CM=CM*CM
      DSE=DSE+BM
C     DSE === SUM OF RESIDUALS   (ST. LINE)
      DSEE=DSEE+CM
C     DSEE === SUM OF RESIDUALS  (SIMPLE EXPO.)
      GO TO 20
   24 BM=Y(I)-YC(I)
      BM=BM*BM
      DSE=DSE+BM
   25 GO TO (20,26),L
   26 XX=2.303*YC(I)
      XY(I)=EXP(XX)
   20 CONTINUE
      GO TO (40,50),L
   40 PRINT11
   11 FORMAT(/5X,'FORECASTED VALUES (ST.LINE)'/5X,28(1H-))
      PRINT12,(YC(I),I=1,NTEN)
   12 FORMAT(/10X,F10.3)
      PRINT13,DSE
   13 FORMAT(/5X,'SUM OF RESIDUALS SQUARE (ST. LINE)=',2X,F20.3)
   50 L=L+1
      GO TO (30,30,31),L
   31 PRINT14
   14 FORMAT(/5X,'FORECASTED VALUES (SIMPLE EXPO.)='/5X,32(1H-))
      PRINT12,(XY(I),I=1,NTEN)
      PRINT15,DSEE
   15 FORMAT(/5X,'SUM OF RESIDUALS SQUARES (SIMPLE EXPO.)=',2X,F20.
      KL=KL+1
      IF(KL-7) 51,51,52
   52 STOP
      END
```

```
C      ***********************************************************
C        PROGRAM-2:CURVE FITTING-PARABOLA AND LOGPARABOLA
C      ***********************************************************
C      PARABOLA Y=A+B*T+C*(T**2),LOGPARABOLA LOG(Y)=A+B*T+C*(T**2)
       DIMENSION Y(40),T(40),YC(40),YL(40),XY(40)
       KL=1
C      INPUT  TOTAL NO. OF YEARS N AND DEMAND Y
   51  READ1,N
    1  FORMAT(I5)
       PRINT1,KL
       PRINT5,N
    5  FORMAT(/5X,'TOTAL NO.OF YEARS=',I5)
       READ2,(T(J),Y(J),J=1,N)
    2  FORMAT(6F10.3)
       PRINT6
    6  FORMAT(/5X,'YEARS',5X,'ENERGY DEMAND'/5X,5(1H-),5X,14(1H-))
       PRINT8,(T(J),Y(J),J=1,N)
    8  FORMAT(/5X,2(5X,F10.3))
       XN=N
        L=1
       PRINT1,L
       GO TO 7
   30  DO 10 J=1,N
       YL(J)=Y(J)
   10  Y(J)=ALOG(Y(J))*0.43429
C      CALCULATIONS OF COEFFTS. A,B AND C
    7  ST3=0.0
       ST4=0.0
       SY=0.0
       ST=0.0
       STY=0.0
       ST2=0.0
       ST2Y=0.0
       DO 3 J=1,N
       SY=SY+Y(J)
       ST=ST+T(J)
       ST2=ST2+T(J)*T(J)
       ST3=ST3+T(J)*T(J)*T(J)
       ST4=ST4+T(J)*T(J)*T(J)*T(J)
       STY=STY+T(J)*Y(J)
    3  ST2Y=ST2Y+T(J)*T(J)*Y(J)
       DE1=ST2*ST4-ST3*ST3
       DE2=ST*ST4-ST3*ST2
       DE3=ST*ST3-ST2*ST2
       DEL=XN*DE1-ST*DE2+ST2*DE3
       A=(SY*DE1-STY*DE2+ST2Y*DE3)/DEL
       B1=STY*ST4-ST2Y*ST3
       B2=SY*ST4-ST2*ST2Y
       B3=SY*ST3-STY*ST2
       B=(XN*B1-ST*B2+ST2*B3)/DEL
       C1=ST2*ST2Y-STY*ST3
       C2=ST*ST2Y-SY*ST3
       C3=ST*STY-SY*ST2
       C=(XN*C1-ST*C2+ST2*C3)/DEL
       PRINT9,A,B,C
    9  FORMAT(/5X,'THE COEFFTS. ARE A, B, C=',2X,3(5X,F10.3))
C      FORECASTED VALUES AND SUM OF SQUARED RESIDUALS
```

```
      DSE=0.0
      DSEE=0.0
      NTEN=N+22
C     NTEN   REPRESENTED  22 YEARS BEYOND  N
      DO 20  I=1,NTEN
      TI=I
      YC(I)=A+B*TI+C*TI*TI
      IF(I-N) 21,21,25
   21 GO TO (24,23),L
   23 BM=Y(I)-YC(I)
      XX=2.303*YC(I)
      XY(I)=EXP(XX)
      BM=BM*BM
      CM=YL(I)-XY(I)
      CM=CM*CM
      DSE=DSE+BM
      DSEE=DSEE+CM
      GO TO 20
   24 BM=Y(I)-YC(I)
      BM=BM*BM
      DSE=DSE+BM
   25 GO TO (20,26),L
   26  XX=2.303*YC(I)
      XY(I)=EXP(XX)
   20 CONTINUE
      GO TO (40,50),L
   40 PRINT11
   11 FORMAT(/5X,'FORECASTED VALUES (PARABOLA)'/5X,28(1H-))
      PRINT12,(YC(I),I=1,NTEN)
   12 FORMAT(/10X,F15.3)
      PRINT13,DSE
   13 FORMAT(/5X,'SUM OF RESIDUALS SQUARED  (PARABOLA)=',2X,F20.3)
   50 L=L+1
      GO TO (30,30,31),L
   31 PRINT14
   14 FORMAT(/5X,'FORECASTED VALUES(LOG PARABOLA)'/5X,32(1H-))
      PRINT12,(XY(I),I=1,NTEN)
      PRINT15,DSEE
   15 FORMAT(/5X,'SUM OF RESIDUALS SQUARED  (LOG PARABOLA)=',2X,F20.3
      KL=KL+1
      IF(KL-7) 51,51,52
   52 STOP
      END
```

```
C     **************************************************************
C      PROGRAM-3(PART-I):CURVE FITTING-MODIFIED EXPONENTIAL
C     **************************************************************
C       GENERAL EQUTION IS  Y=A+B*X**T
C       SIMPLE MODIFIED EXPO.   Y=Y
C      LOGISTIC  Y=1.0/Y   , GOMPRETZ  Y= LOG(Y)
C      INPUT  NO.OF YEARS  N,WEIGHTS  W,DEMAND  CY  YEARWISE
C       AND  YEARST FROM 1 TO N
      DIMENSION CY(40),W(40),T(40),SY(40),B(40),A(40),DEL(40)
   30 READ50,N
   50 FORMAT(2I5)
      PRINT100,N
  100 FORMAT(/5X,'TOTAL NO. OF YEARS=',2X,I5)
      KL=1
C       KL     ISCOUNT FOR SETS OF DATA
      READ1,(T(J),CY(J),J=1,N)
    1 FORMAT(6F10.3)
      PRINT101
  101 FORMAT(/5X,'YEARS',10X,'DEMAND'/5X,5(1H-),10X,7(1H-))
      PRINT400,(T(J),CY(J),J=1,N)
  400 FORMAT(/5X,F10.3,10X,F10.3)
      L=1
   52 PRINT50,L,KL
      DO 51 J=1,N
      GO TO (40,41,42),L
   40 SY(J)=CY(J)
      W(J)=1.0
      GO TO 51
   41 SY(J)=1.0/CY(J)
      W(J)=1.0
      GO TO 51
   42 SY(J)=ALOG(CY(J))*0.4343
      W(J)=1.0
   51 CONTINUE
C     INITIAL VALUE OF X IS 0.55, ICNCREMENT IS 0.05
      K=1
      X=0.55
      DX=0.05
   16 X1=X
C     CALCULATION OF COEFFS. A,B AND  DEL
      DO 9 I=1,9
      SW=0.0
      SWY=0.0
      SWE=0.0
      SWYE=0.0
      SWY2=0.0
      SWE2=0.0
      RHO=ALOG(X)
      DO 2 J=1,N
      EX=EXP(RHO*T(J))
      SW=SW+W(J)
      SWYE=SWYE+W(J)*SY(J)*EX
      SWY=SWY+W(J)*SY(J)
      SWE=SWE+W(J)*EX
      SWE2=SWE2+W(J)*EX*EX
    2 SWY2=SWY2+W(J)*SY(J)*SY(J)
      B1=SW*SWYE-SWY*SWE
```

```
      B2=SW*SWE2-SWE*SWE
      B(I)=B1/B2
      A(I)=(SWY-B(I)*SWE)/SW
      DEL1=SWY2+A(I)*A(I)*SW+B(I)*B(I)*SWE2
      DEL2=2.0*A(I)*B(I)*SWE-2.0*A(I)*SWY-2.0*B(I)*SWYE
      DEL(I)=DEL1+DEL2
C     SELECT A,B CORRESPONDING TO MINIMUM  DEL
C      ACCURACY INX IS 0.0004  (FOR  DEL)
    9 X=X+DX
      DELM=DEL(1)
      I1=1
      DO 15 I=2,9
      IF(DEL(I)-DELM) 11,11,15
   11 DELM=DEL(I)
      I1=I
   15 CONTINUE
      AI1=I1-1
      XM=X1+DX*AI1
      PRINT200
  200 FORMAT(/5X,'FOLLOWING VALUES ARE CORRESPONDING TO MIN. DEL'/4X,
     1(1H-))
      PRINT3,XM,DELM,A(I1),B(I1),AI1,DX
    3 FORMAT(/2X,'XM=',F15.8,2X,'DELM=',F20.8,2X,'CONSTANT A =',F15.8
     12X,'CONSTANT B =',F17.8,2X,'AI1=',F5.2,2X,'DX=',F8.4)
      XM1=XM-DX
      DX=DX*0.2
      X=XM1+DX
C     IF X IS NOT WITHIN 0.1004 AND 0.9996, CURVE FIT IS NOT POSSIBLE
      IF(DX-0.00035) 17,16,16
   17 IF(XM-0.10035) 18,18,19
   19 IF(XM-0.9996) 20,18,18
   20 GO TO (23,24),K
   23 IF(XM-0.5004) 21,21,24
   21 X=0.15
      DX=0.05
      K=2
      GO TO 16
   18 PRINT 29
   29 FORMAT(/20X,'NO FIT IS POSSIBLE')
   24 PRINT300,XM
  300 FORMAT(/5X,'XM=',F15.8)
      L=L+1
      IF(L-3) 52,52,37
   37 KL=KL+1
      IF(KL-7) 30,30,32
   32 STOP
      END
```

```
C     **************************************************************
C      PROGRAM-3(PART-II):CURVE FITTING-MODIFIED EXPONENTIAL
C     **************************************************************
C      CALCULATION OF FORECASTED VALUES AND SUM OF SQUARED RESIDUALS
C      VALUES OF A,B AND R TAKEN FROM PROGRAM-3(PART-I)
       DIMENSION T(40),CY(40),YC(40),SY(40)
C      INPUT NO. OF YEARS ANDDEMAND YEAR WISE CY(J)
C      AND COEFFT. A,B AND R
       KL=1
   60  READ1,N
    1  FORMAT(2I5)
       PRINT100,N
  100  FORMAT(/5X,'TOTAL NO. OF YEARS=',2X,I5)
       READ2,(T(J),CY(J),J=1,N)
    2  FORMAT(6F10.3)
       PRINT101
  101  FORMAT(/5X,'YEARS',10X,'DEMAND'/5X,5(1H-),10X,7(1H-))
       PRINT400,(T(J),CY(J),J=1,N)
  400  FORMAT(/5X,F10.3,10X,F10.3)
       L=1
   50  PRINT1,L,KL
       READ3,A,B,R
    3  FORMAT(3F17.8)
       PRINT200,A,B,R
  200  FORMAT(/5X,'A=',F17.8,5X,'B=',F17.8,5X,'R=',F17.8)
C       FORECASTED VALUES AND SUM OF SQUARED RESIDUALS
       DSE=0.0
        N5=N+22
C         N5   REPRESENTS 22 YEARS BEYOND N
       RHO=ALOG(R)
       TTJ=0.0
       DO 20 J=1,N5
       TTJ=TTJ+1.0
       EX=EXP(RHO*TTJ)
       YC(J)=A+B*EX
       GO TO (24,23,22)L
   23  SY(J)=1.0/YC(J)
       IF(J-N) 26,26,20
   22  XX=2.303*YC(J)
       SY(J)=EXP(XX)
       IF(J-N) 26,26,20
   26  BM=CY(J)-SY(J)
       GO TO 30
   24  IF(J-N) 19,19,20
   19  BM=CY(J)-YC(J)
   30  BM=BM*BM
       DSE=DSE+BM
   20  CONTINUE
       PRINT5,DSE
    5  FORMAT(F20.8)
       GO TO (40,41,41) L
   41  PRINT3,(SY(J),J=1,N5)
   40  PRINT3,(YC(J),J=1,N5)
       L=L+1
       IF(L-3) 50,50,51
   51  KL=KL+1
       IF(KL-7) 60,60,61
```

```
C     ******************************************************
C       PROGRAM-4:MULTIPLE LINEAR REGRESSION ALGORITHM
C     *****************************************************
C       MAIN LINE PROGRAM FOR SUBROUTINE L I N R E G
        DIMENSION X(10,6),Y(10),A(36),B(6),XBAR(6),YHAT(10),AA(6,6)
   10 READ1,NA,NX,M
    1 FORMAT(8I10)
    TYPE*,NA,NX,M
      NN=NA*NA
      IF(NA) 999,999,20
   20 DO 100 I=1,NX
      READ2,(X(J,I),J=1,M)
    2 FORMAT(7F10.3)
    TYPE*,(X(J,I),J=1,M)
  100 CONTINUE
C     THIS SECTION ****SETS UP FUNCTIONS****
      DO 200 K=1,M
      X(K,4)=X(K,2)**2
      X(K,5)=X(K,1)*X(K,2)
  200 CONTINUE
      READ3,(Y(I),I=1,M)
    3 FORMAT(7F10.3)
    TYPE*,(Y(I),I=1,M)
      CALL LINREG(X,Y,NA,M,A,B,XBAR,YHAT,AA,NN)
      GO TO 10
  999 STOP
      END
      SUBROUTINE LINREG(X,Y,N,M,A,B,XBAR,YHAT,AA,N2)
      DIMENSION X(10,6),Y(10),A(36),B(6),XBAR(6),YHAT(10),AA(6,6)
      PRINT1
    1 FORMAT(/10X,'MULTIPLE LINEAR REGRESSION ALGORITHM'/8X,38(1H-))
C     CALCULATION OF AVERAGEVALUES OF X AND Y
       TYPE*,(Y(L),L=1,M),M,N
    SUMY=0.0
    DO 300 K=1,M
300 SUMY=SUMY+Y(K)
    YBAR=SUMY/FLOAT(M)
    DO 200 I=1,N
    SUMX=0.0
    DO 100 J=1,M
100 SUMX=SUMX+X(J,I)
200 XBAR(I)=SUMX/FLOAT(M)
      PRINT2
    2 FORMAT(//2X,'VARIABLE AVERAGE VALUES'/1X,24(1H-))
      PRINT3,(II,XBAR(II),II=1,N)
    3 FORMAT(/,3(2X,'XBAR(',I2,')=',F20.8))
      PRINT4,YBAR
    4 FORMAT(/2X,'YBAR=',F15.8)
C     CALCULATION OF REGRESSION MATRIX
      KK=1
      DO 500 I=1,N
      DO 500 J=1,N
      SUMA=0.0
      SUMB=0.0
      DO 400 K=1,M
      SUMA=SUMA+(X(K,I)-XBAR(I))*(X(K,J)-XBAR(J))
  400 SUMB=SUMB+(Y(K)-YBAR)*(X(K,I)-XBAR(I))
```

```
      AA(I,J)=SUMA
      A(KK)=SUMA
      KK=KK+1
  500 B(I)=SUMB
      PRINT5
    5 FORMAT(//10X,'A--MATRIX'/8X,10(1H-))
      DO 550 II=1,N
  550 PRINT6,(AA(II,JJ),JJ=1,N)
    6 FORMAT(/,8(2X,E15.7))
      PRINT7
    7 FORMAT(//,10X,'B--MATRIX'/8X,10(1H-))
      PRINT6,(B(KK),KK=1,N)
C     SOLVING REGRESSION MATRICES FOR COEFFICIENTS
      CALL SIMQ(A,B,N,KS,N2)
      SUMX=0.0
      DO 600 I=1,N
  600 SUMX=SUMX+B(I)*XBAR(I)
      AZERO=YBAR-SUMX
      PRINT8
    8 FORMAT(/10X,'VALUES OF REGRESSION COEFFICIENTS'/2X,35(1H-))
      PRINT9,(JJ,B(JJ),JJ=1,N)
    9 FORMAT(/,2(2X,'AHAT(',I2,')=',F20.8,8X))
      PRINT10,AZERO
   10 FORMAT(/,2X,'AZERO=',F20.8)
C     CALCULATION OF S AND R TEST VALUES
      STEST=0.0
      DO 800 J=1,M
      SUMS1=0.0
      DO 700 K=1,N
  700 SUMS1=SUMS1+B(K)*X(J,K)
      YHAT(J)=AZERO+SUMS1
      DIFF=(Y(J)-YHAT(J))**2
  800 STEST=STEST+DIFF
      SUMST=0.0
      DO 900 I=1,M
  900 SUMST=SUMST+(Y(I)-YBAR)**2
      SUMSR=SUMST-STEST
      RTEST=SUMSR/SUMST
      PRINT11
   11 FORMAT(////,5X,'EXPERIMENTAL VALUES',18X,'REGRESSION VALUES')
      PRINT15
   15 FORMAT(4X,20(1H-),16X,18(1H-))
      DO 1000 KK=1,M
 1000 PRINT12,KK,Y(KK),KK,YHAT(KK)
   12 FORMAT(/,2X,'Y(',I3,')=',F15.8,10X,'YHAT(',I3,')=',F15.8)
      PRINT13,SUMST,STEST,RTEST
   13 FORMAT(///,2X,'SUMST=',F20.8,/,2X,'S=',F20.8,10X,'R**2=',F20.8)
      RETURN
      END
      SUBROUTINE SIMQ(A,B,N,KS,NS)
      DIMENSION A(36),B(6)
C     FORWARD SOLUTION
      TOL=0.0
      KS=0
      JJ=-N
      DO 65 J=1,N
      JY=J+1
```

```
      JJ=JJ+N+1
      BIGA=0.0
      IT=JJ-J
      DO 30 I=J,N
C     SEARCH FOR MAX. COEFF. IN COLUMN
      IJ=IT+I
      IF(ABS(BIGA)-ABS(A(IJ))) 20,30,30
   20 BIGA=A(IJ)
      IMAX=I
   30 CONTINUE
C     TEST FOR PIVOT LESS THAN TOLERANCE(SINGULAR MATRIX)
      IF(ABS(BIGA)-TOL) 35,35,40
   35 KS=1
      RETURN
C     INTERCHANGE ROWS IF NECESSARY
   40 I1=J+N*(J-2)
      IT=IMAX-J
      DO 50 K=J,N
      I1=I1+N
      I2=I1+IT
      SAVE=A(I1)
      A(I1)=A(I2)
      A(I2)=SAVE
C     DIVIDE EQATION BY LEADING COEFF.
   50 A(I1)=A(I1)/BIGA
      SAVE=B(IMAX)
      B(IMAX)=B(J)
      B(J)=SAVE/BIGA
C     ELIMINATE NEXT VARIABLE
      IF(J-N) 55,70,55
   55 IQS=N*(J-1)
      DO 65 IX=JY,N
      IXJ=IQS+IX
      IT=J-IX
      DO 60 JX=JY,N
      IXJX=N*(JX-1)+IX
      JJX=IXJX+IT
   60 A(IXJX)=A(IXJX)-(A(IXJ)*A(JJX))
   65 B(IX)=B(IX)-(B(J)*A(IXJ))
C     BACK SUBSTITUTION
   70 NY=N-1
      IT=N*N
      DO 80 J=1,NY
      IA=IT-J
      IB=N-J
      IC=N
      DO 80 K=1,J
      B(IB)=B(IB)-A(IA)*B(IC)
      IA=IA-N
   80 IC=IC-1
      RETURN
      END
```

CHAPTER - V

CONCLUSION

5.1 The basic aim of the thesis is to forecast the energy requirement and peak load of U.P. Power System, for medium and long term and comparing the results with the forecast obtained by Central Electricity Authority (CEA). The results of medium and long term forecast of energy requirement and peak load of U.P. Power System by three different methods namely ; Scheer's Formula, Regression Method and Historical Trend Method, are summarised in table-4.10. The last two columns of table-4.10, give the corresponding forecast given by CEA /19/. The forecast obtained by CEA up to the year 1983-84, is based on class-wise consumption and partly on load survey methods. Beyond 1983-84, they work out the forecast on the basis of historical trend method and Scheer's formula, by projecting the estimates of 1983-84. The forecast indicated by CEA is on the basis of unrestricted power supply. As almost every year there is restriction imposed on the use of electric power in U.P., the computed forecast by all the above three methods, shown in table-4.10, will be lesser than one obtained by CEA. Thus, from table-4.10, it can be concluded that Regression Method and Historical Trend Method tend to

Table-4.10 : Forecasted energy requirement and peak load for U.P. Power System

Year	Scheer's formula		Regression method		Historical trend method		Forecast given by CEA	
	Energy requirement	Peak load	Energy requirement	Peak load	Energy requirement	Peak load	Energy requirement	Peak load
1983-84	20949	3986	20571	3914	18225	3468	23082	4457
1988-89	33598	6392	37590	7152	38147	7258	38890	7474
1993-94	52487	9986	71679	13638	90749	17266	64100	12236

give higher values of forecast for long term. The difference between forecast, computed by all the three methods are obtained by CEA is because of not taking into account the generation by private agencies and licensees, due to non-availability of data. This difference can also be attributed to the assumptions made regarding load factor, auxiliary consumption and percentage T & D losses etc. Thus, it can be concluded that the best estimate for long term is only provided by Scheer's formula.

In regard to medium term forecast, it may be seen from table-4.10, that the forecast made by Scheer's formula is very close to that made by other two methods establishing the fact that the Scheer's formula is most suitable for forecasting long term as well as medium term power requirement.

5.2 There is no ideal method of forecasting load, which could take all the economic factors into consideration to suit national/state conditions. Forecasting on the basis of correlationship between development of electricity and development of economic factors, is supposed to be best. In India, no such explicit relationship between some economic factor and total electricity utilisation, has been established. Here, an attempt has been made to establish such relationship by correlating electricity

utilisation with state income and population, using some regression models. One of the model gave results very near to corresponding results given by Scheer's formula for medium term. But here, the aspects like income distribution pattern, urban-rural ratio of population and cost of service-connection etc. have been neglected, which have significant impact on the growth of electricity demand.

Furthermore, better relationships between development of electricity and development of economic factors, can be established by considering some more economic factors like employment, appliance saturation, weather data etc. The projections of economic factors usually considered in load forecasting are based on past pattern and human judgement. Instead of this, if, the economic factor can themselves be forecasted by using an appropriate forecasting technique, it is expected that the regression method would yield better results. This inturn becomes another forecasting problem for which no well defined method exists. Similarly, the load factor, auxiliary consumption and percentage of T & D losses, which at present are assumed, can also be forecasted to achieve better results.

5.3 The present set up of our planning is based on the 'distinct five year plans'. All the developments are guided by these plans only. So, an accurate five year

forecast at the begining of each plan period followed by a mid plan forecast is much more essential than the long term forecasting. This, also takes into considerations, the success achieved in first two or three years of the plan. This is ideal for our Indian conditions. It is, therefore, felt that our efforts should be directed towards achieving a greater degree of accuracy in short term forecasting before going in for long term forecast, until we arrive at the stage of stable economy.

APPENDIX - A

TREND CURVES AND THEIR CHOICE

A.1 The trend curve /24/ that are frequently used for the analysis of economic data are: (i) Polynomials, (ii) Exponential, (iii) Modified exponential etc.

A.1.1 Polynomials:

(i) Straight line:

Demand = a + bt, where a and b are constants. The slope of straight line is constant. It means that the demand is increasing by a constant amount each year. If the slope is plotted against time a horizontal straight line is obtained and this is the slope characteristic.

(ii) Parabola:

Demand = $a + bt + ct^2$, where a, b and c are constants. The slope of parabola changes uniformly with time, and if the slope is plotted against time a straight line at an angle to the horizontal is obtained.

A.1.2 Exponential:

(i) Simple exponential:

Log (demand) = a + bt, where a and b are constants.

Here demand increases by a constant proportion each year, and the ratio of the slope of the demand to the demand is constant. The moving average gives an estimate of the demand and the ratio of the slope to the moving average is plotted against time, results in a horizontal straight line which is the slope characteristic.

(ii) Logarthimic parabola:

Log (demand) = $a + bt + ct^2$, where a, b and c are constants. For this, the ratio of slope of the demand, to the demand varies linearly with time. If the ratio of slope of the demand to the moving average is plotted against time, a sloping straight line will be obtained as slope characteristic.

A.1.3 Modified exponential :

The use of modified exponential trend curves implies the existence of an upper limit to demand which is approached asymptotically.

(i) Simple modified exponential:

Demand = $a - br^t$, where a, b and r are positive constants and r is less than 1. The logarithm of the slope of demand when plotted against time gives a straight line, sloping down to the right, which

is slope characteristic.

(ii) Gompertz :

Log (demand) = $a - br^t$, where a, b and r are positive constants and r is less than 1. The logarithm of the ratio of the slope to the moving average when plotted against time gives a straight line sloping down to the right, which is slope characteristic.

(iii) Logistic :

Demand = $1/(a + br^t)$, where a, b and r are positive constants and r is less than 1. The logarithm of the ratio of the slope to the square of the moving average, when plotted against time, will give a straight line sloping to the right, which is slope characteristic.

A.2 CHOICE OF TREND CURVE

The trend curves are preferably established by means of least square method. The fitting of a mathematical curve implies two assumptions. The first assumption concerns the type of curve which is chosen to fit the demand figures. The second is that the chosen curve will, when extrapolated, represent the picture of future demand.

The object of a forecast is to estimate the change

from the current to the future position. When a trend curve is fitted to demand figures and extrapolated to provide a forecast, its realiability will be dependent on the accuracy of the slope of the trend. If the trend is linear the estimates of the slope will be equal. If the trend is modified exponential the estimates of the slope will be changing in a specified manner. The slope of the demand is, therefore, a criterion for the selection of the trend curve and forms the basis of the technique for choosing the curves.

When trend curve are fitted to the set of data, it is usually found that the closeness of fit is approximately the same for all the curves. There will be little to choose between the curves as representation of the actual data. When the curves are extrapolated they diverge. Even a small extrapolation may lead to unacceptable large divergence. Therefore, it is necessary to find the applicability of the trend curves to be used for forecasting.

Assuming the difference between the curve may be very small which can be neglected over the range of data, the projection of curve into future will depend on the rate of change of various curves. For any curve $Y = [f(t)]^{*}$, the rate of change at any point of the curve can be found out by the values of it's derivative $dy/dt = f'(t)$ at that point. For the curves, the difference between predictions

will arise from the differences between derivatives. It is, therefore, necessary to compare the curve representing the rate of change of demand with the derivatives to test the suitability of the curve for prediction. The easiest curve which can be recognised is straight line. Therefore, for each curve the transformation of the derivative which will yield a straight line with 't' (time) as independent variable, isfound. Each such transformation is applied to the estimated rates of change of the datafor each year of the period and the results are plotted against time. It is then decided by inspection whether for any transformation of the rate of change, the plotted values appear to approximate to a straight line. Where a straight line is a reasonable fit, the corresponding curve may be expected to be a satisfactory predictor. The rate of change is the slope and the transformation obtained to characterise the curves are called slope characteristics. The various slope characteristics of trend curves are summarised in table-A.1.

In order to determine the slope characteristics, it is necessary to calculate the slope for the set of demand data. Because of the fluctuations from year to year, the actual demand and the simple differences are not considered satisfactory for the purpose and some smoothing is done by using moving averages. To obtain an estimate of the slope for a given year, a short period

detailed in reference /25/. The approach results in a set of two simultaneous equations for N years data.

$$ty = aN + b\sum t \tag{A.1}$$

$$\sum ty = a\sum t + b\sum t^2 \tag{A.2}$$

Solving above equations for a and b,

$$a = \frac{(\sum y)(\sum t^2) - (\sum t)(\sum ty)}{N\sum t^2 - (\sum t)^2} \tag{A.3}$$

$$b = \frac{N\,(\sum ty) - (\sum t)(\sum y)}{N\sum t^2 - (\sum t)^2} \tag{A.4}$$

Where $\sum$ stands for sum of all such items, from t = 1 to t = N. In the program a and b have been calculated using equations-(A.3) and (A.4) respectively. Further the calculated values of a and b are used to obtain the forecast values. In addition, the sum of squared residuals i.e. $\sum(y - y_{cal})^2$, (where y_{cal} is calculated value of y) is also computed. The program is evolved so that first the straight line function is fitted and then exponential function.

Program-2 : Curve fitting-Parabola and Log parabola : The mathematical function is $y = a + bt + ct^2$, where a, b and c are constants. y = y, represents parabola and y = log y, represents log parabola. The function is fitted by least square method. For N years data the

resulting simultaneous equations are :

$$ty = aN + b\sum t + c\sum t^2 \tag{A.5}$$

$$\sum ty = a\sum t + b\sum t^2 + c\sum t^3 \tag{A.6}$$

$$\sum t^2y = a\sum t^2 + b\sum t^3 + c\sum t^4 \tag{A.7}$$

Writing above equations in matrix form and solving for a, b and c

$$a = \frac{\left\{\sum y\left[(\sum t^2)(\sum t^4) - (\sum t^3)(\sum t^3)\right] - \sum ty\left[(\sum t)(\sum t^4) - (\sum t^3)(\sum t^2)\right] + \sum t^2y\left[(\sum t)(\sum t^3) - (\sum t^2)(\sum t^2)\right]\right\}}{\Delta} \quad \ldots\ldots\ldots(A.8)$$

$$b = \frac{\left\{N\left[(\sum ty)(\sum t^4) - (\sum t^2y)(\sum t^3)\right] - \sum t\left[(\sum y)(\sum t^4) - (\sum t^2y)(\sum t^2)\right] + \sum t^2\left[(\sum y)(\sum t^3) - (\sum ty)(\sum t^2)\right]\right\}}{\Delta} \quad \ldots\ldots\ldots(A.9)$$

$$c = \frac{\left\{N\left[(\sum t^2)(\sum t^2y) - (\sum t^3)(\sum ty)\right] - \sum t\left[(\sum t)(\sum t^2y) - (\sum t^3)(\sum y)\right] + \sum t^2\left[(\sum t)(\sum ty) - (\sum t^2)(\sum y)\right]\right\}}{\Delta} \quad \ldots\ldots\ldots(A.10)$$

Where, $\Delta = N\left[(\sum t^2)(\sum t^4) - (\sum t^3)(\sum t^3)\right] - \sum t \left[(\sum t)(\sum t^4) - (\sum t^3)(\sum t^2)\right] + \sum t^2\left[(\sum t)(\sum t^3) - (\sum t^2)(\sum t^2)\right]$ .... (A.11)

In the program, the values of a, b and c are calculated directly using above relationships. Further, the computed values of the constants are used to obtain forecast values. In addition the sum of the squared residuals for the data is also computed. The program is evolved so that first, parabola and then log parabola is fitted.

Program-3 (Part-I) : Curve fitting - Modified Exponential : The mathematical function is $y = a + bR^t = a + b\exp(\rho t)$, where a, b and R are constants with $1 > R > 0$, $\rho = \ln R$, t is time measured from some arbitrary zero. If y is demand at time t,

$y = \mathrm{Log}_{10}\, y$, for the Gompertz curve.

$y = y$, for the **S**imple Modified Exponential.

$y = 1/y$, for the Logistic curve.

When for a set of data above three curves are fitted the assumptions regarding variability of the data will be different. For the Gompertz, the inference is that the coefficient of variation of demand data is constant whilst the Simple Modified Exponential implies that the variance of demand data is constant. For Logistic, the assumption is that the coefficient of variation is inversely proportional to the absolute magnitude of the demand. Though, the assumptions are reasonable for Gompertz and

Simple Modified Exponential, for Logistic such an assumption would lead to give undue weight to the early demand data. In order to avoid this and to fit the above three curves based on similar assumptions, it is necessary to apply a weighting factor w_j , such that /24/

$$z_j = y_j \sqrt{w_j} \tag{A.12}$$

The curves are fitted by least square method i.e., by minimising

$$\Delta = \sum \left[w_j \left\{ y_j - a - b \exp (\rho t_j) \right\}^2 \right] \tag{A.13}$$

The normal equations are therefore,

$$\left.\begin{aligned}
&-2 \sum \left[w_j \left\{ y_j - a - b \exp (\rho t_j) \right\} \right] = 0 \\
&-2 \sum \left[w_j \exp (\rho t_j) \left\{ y_j - a - b \exp (\rho t_j) \right\} \right] = 0 \\
&-2\, b \sum \left[w_j t_j \exp (\rho t_j) \left\{ y_j - a - b \exp (\rho t_j) \right\} \right] = 0
\end{aligned}\right\} \tag{A.14}$$

or

$$\left.\begin{aligned}
&a \sum w_j + b \sum w_j \exp (\rho t_j) = \sum w_j y_j \\
&a \sum \left\{ w_j \exp (\rho t_j) \right\} + b \sum \left\{ w_j \exp (2 \rho t_j) \right\} \\
&\qquad = \sum \left\{ w_j y_j \exp (\rho t_j) \right\} \\
&ab \sum \left\{ w_j t_j \exp (\rho t_j) \right\} + b^2 \sum \left\{ w_j t_j \exp (2 \rho t_j) \right\} \\
&\qquad = b \sum \left\{ w_j y_j t_j \exp (\rho t_j) \right\}
\end{aligned}\right\} \tag{A.15}$$

If the curves are to be of the required form, approaching a limiting value of large t, the value of R must be between 0 and 1 and usually between 0.5 and 1. For any given value of R (and therefore, of $\rho = \ln R$), a and b and hence Δ, may be found from:

$$a \sum w_j + b \sum w_j \exp(\rho t_j) = \sum w_j y_j$$

$$a \sum \{w_j \exp(\rho t_j)\} + b \sum \{w_j \exp(2\rho t_j)\} \tag{A.16}$$

$$= \sum \{w_j y_j \exp(\rho t_j)\}$$

Solving above equations, the values of a and b are obtained as :

$$b = \frac{\sum w_j \sum\{w_j y_j \exp(\rho t_j)\} - \sum w_j y_j \sum\{w_j \exp(\rho t_j)\}}{\sum w_j \sum\{w_j \exp(2\rho t_j)\} - \left[\sum\{w_j \exp(\rho t_j)\}\right]^2}$$

.... (A.17)

$$a = \left[\sum w_j y_j - b \sum\{w_j \exp(\rho t_j)\}\right] / \sum w_j \tag{A.18}$$

and the value of Δ is evaluated by substituting the values of a and b in equation-(A.13).

$$\Delta = \left[\sum\{w_j y_j^2\} - \{\sum w_j y_j\}^2 / \sum w_j\right] - b\left[\sum\{w_j y_j \exp(\rho t_j)\} - \sum w_j y_j \sum\{w_j \exp(\rho t_j)\} / \sum w_j\right]$$

.... (A.19)

The method of solution adopted is to evaluate by equations-(A.17), (A.18) and (A.19) for a series of values of R and to select the value of R, giving the lowest value of Δ .

Since, normally $0.5 < R < 1.0$, the initial search is made with 9 values of R = 0.55 (0.05) 0.95. The step length is then divided by 5 and the search is repeated to a further set of 9 values centred around the selected value of R. This procedure is repeated till the step length is small enough to give the required accuracy in R. Normally 4 sets of values of R is tested giving a step length of 0.0004 in the last set.

If the final R is the largest tried one further set of values is tried and if R is still at its highest possible value 'No fit is possible' is printed.

If the final R is the lowest tried the whole procedure is repeated starting from R = 0.15 (0.05) 0.55. If after this the final R is still the lowest tried 'No fit is possible' is printed. This procedure though some what involves quite amount of computations, is robust against possible oddities in the behaviour of the function /24/.

The final minimum value of delta (Δ) gives the sum of squares of z about its expected value.

The program is evolved so, to fit the curves in

the order of Simple Modified Exponential, Logistic and the Gompertz.

Program-3 (Part-II) : This is the continuation of the program-3 (Part-I). After evaluating constants a, b and R the results are used to obtain the forecast values and to compute the sum of the squared residuals.

APPENDIX - B

MULTIPLE LINEAR REGRESSION

The regression analysis is a technique to relate one variable (say Y) to the other (say X). With this relationship the values of first variable (Y, usually referred as dependent variable) can be estimated for future course of time, for given values of second variable (X, usually referred as independent variable) in that time period. If this relationship is assumed to be linear then regression of Y on X will be called linear regression. In the other way, this relationship expresses the effect of values of X, on the values of Y. This relationship may be different one, when X is regressed on Y.

In practice, knowledge of independent variable X, is not only sufficient to estimate dependent variable Y. Y may be more precisely estimated with the knowledge of more than one independent variables (say X_1, X_2....... etc.). In this case we might try to relate Y, with more than one independent variables and is referred as Multiple Linear Regression and the coefficients of independent variables in the regression equation are called regression coefficients. These coefficients are usually determined by least square method.

B.2 Program-4 : Multivariable linear regression /21/

Program-4, in section-4.6, solves for the coefficients in a multivariable, linear regression equation of the form

$$\hat{Y} = \hat{A}_0 + \hat{A}_1 F_1(\underline{X}) + \hat{A}_2 F_2(\underline{X}) + \ldots\ldots + \hat{A}_M F_M(\underline{X}) \qquad (B.1)$$

Where $\hat{Y}$, is the Model dependent variable. $\hat{A}_j$, are the unknown coefficients, $j = 0, 1, 2, \ldots. M$. F_j, are function of the independent variable X_i, $i = 1, 2, 3, \ldots.K$, $j = 1, 2, \ldots. M$.

The method consists of minimising a least squares objective functions S, of the form

$$S = \sum_{i=1}^{N} (Y_i - \hat{Y}_i)^2 \qquad (B.2)$$

Where Y_i, are the experimental observed values of the dependent variable. The algorithm proceeds as follows.

(i) The normal equations are obtained by setting $\partial S/\partial \hat{A}_j = 0$, $j = 0, 1, 2, \ldots.. M$ and eliminating the $\partial S/\partial \hat{A}_0 = 0$ equation,

$$(\underline{F}^t \; \underline{F}) \; \underline{\hat{A}} = \underline{F}^t \; \underline{Y} \qquad (B.3)$$

Where

$$\underline{F} = \begin{bmatrix} (F_{1,1} - \bar{F}_1) & (F_{1,2} - \bar{F}_2) & ---- & (F_{1,M} - \bar{F}_M) \\ (F_{2,1} - \bar{F}_1) & (F_{2,2} - \bar{F}_2) & ---- & (F_{2,M} - \bar{F}_M) \\ \vdots & \vdots & & \vdots \\ (F_{N,1} - \bar{F}_1) & (F_{2,N} - \bar{F}_2) & ---- & (F_{N,M} - \bar{F}_M) \end{bmatrix}$$

$$\underline{Y} = \begin{bmatrix} (Y_1 - \overline{Y}) \\ (Y_2 - \overline{Y}) \\ \vdots \\ (Y_N - \overline{Y}) \end{bmatrix} \qquad \underline{\hat{A}} = \begin{bmatrix} \hat{A}_1 \\ \hat{A}_2 \\ \vdots \\ \hat{A}_M \end{bmatrix}$$

$\underline{F}^t$ is the transpose of the $\underline{F}$ matrix, $\overline{Y}$ and $\overline{F}_j$ are mean values

(ii) For the linear regression model, the normal equation will be linear, with the unknowns being the $\underline{\hat{A}}$ vector. Thus any appropriate linear algebric equation solution scheme may be used to solve for the unknown coefficients $\hat{A}_1$ to $\hat{A}_M$. $\hat{A}_0$ is obtained from

$$\hat{A}_0 = \overline{Y} - \sum_{j=1}^{M} \hat{A}_j \overline{F}_j \tag{B.4}$$

(iii) Two tests are often performed to determine the validity of the model. First, the least squares objective function S, is evaluated. For a perfect fit, this value would be zero. Secondly, the 'multiple correlation coefficient' R^2, may be calculated

$$R^2 = \frac{\text{Sum of Squares due to regression (SUMSR)}}{\text{Sum of squares corrected total (SUMST)}}$$

$$\text{Where SUMSR} = \underline{\hat{A}}^t (\underline{F}^t \underline{Y}) = \sum_{i=1}^{N} (\hat{Y}_i - \overline{Y})^2 \tag{B.5}$$

$$SUMST = \underline{Y}^t \, \underline{Y} = \sum_{i=1}^{N} (Y_i - \overline{Y})^2 \qquad (B.6)$$

The values of R^2 will be between 0 and 1, with $R^2 = 1$, corresponding to a perfect fit.

The program consists of a short main program, the subroutine LINREG called from main program and the subroutine SIMQ called from LINREG. All data is supplied through the main program and the functions of X are set up there. Subroutine LINREG sets up the normal equations, performs tests and prints out the results. Subroutine SIMQ solves the normal (linear algebric) equations for $\hat{\underline{A}}$ vector of coefficients by Gauss - Jordan elimination method.

REFERENCES

1. S.D. Kushare; 'Load forecasting Techniques', CBIP 41st Annual Board Session.

2. M.K. Mohan, T. Devnath, H.H. Vora and S.R. Gatta; 'Long Term forecasting - An Indian Case Study', IFAC Symposium on Computer application in large scale Power-Systems 1979, Vol.I.

3. A.R.N.Rao; 'Load forecasting', CBIP 41st Annual Board Session.

4. K.W. Edwin, M.EL - Sayed and H.H. Rollinger; 'Application of a combined Short-term Load Forecasting Alogrithm to different Power-System Utilities', IFAC Symposium on Computer application in large-scale Power-Systems 1979, Vol.I.

5. R.L. Mahajan; 'Load forecasting and its Techniques', CBIP 41st Annual Board Session.

6. 'R.E.C.- Seminar on Rural Electrification and Project Appraisal', held by R.E.C. of India in New Delhi, 1971.

7. 'CEA - Guide lines for Long-term forecasting', CEA Power Survey Directorate, August 1974.

8. K. Venkataraman; 'Some aspects of forecasting Power-demand', 41st Annual Board Session.

9. Lathan Jr., J.H. Nordman, D.A. Voorhis, J.S. Curtis and Plant E; 'Probability Approach to Electricity forecasting', IEEE Trans. on Power Apparatus and Systems, Vol.87, Feb.1968.

10. H.N. Ramchandra Rao and D.K. Subramaniam; 'Modern techniques applied to electric Load forecasting', CBIP 41st Annual Board Session.

11. Robert L. Sullivan; 'Power System Planning', McGraw-Hill International Book Company.

12. Gaucer; 'Electrical Power Industries in Canada', Mechanical Power, June 1961.

13. ECAFE - 'Problem of forecasting energy demand in the ECAFE region', Paper No.6, Section 1A, W.P.C. Japan 1966.

14. Solomon S.,and Scrutton G; 'Effect of Industries on Regional electrical Load forecasting', Engineering journal, Canada, Vol.49, No.10, October 1966.

15. T.N. Idnani; 'Load forecasting', Journal of Institution of Engineers (India), Vol.43, No.2, 1962.

16. New W.R.; 'Load forecasting on the T.V.A. System-Part-III-Residential', IEEE Conference Paper No. CP-63-222, Feb. 1963.

17. N.R. Draper and H. Smith; 'Applied Regression Analysis', New York Wiley, 1966.

18. A.Shankran ; 'A Survey of present and future Power demands of India', Indian journal of Power and River valley development, Sept. 1959.

19. 'Tenth Annual Electric Power Survey', Govt. of India Publication, 1977.

20. K.D. Gupta; 'Problem of Estimating long term requirement of India', Indian journal of Power and River valley development, April 1976.

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